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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION SPACE STATION PROPOSAL

HEARINGS

BEFORE A

SUBCOMMITTEE OF THE COMMITTEE ON APPROPRIATIONS UNITED STATES SENATE

ONE HUNDREDTH CONGRESS

FIRST SESSION

SPECIAL HEARING

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION SPACE STATION PROPOSAL

FRIDAY, MAY 1, 1987

U.S. SENATE,
SUBCOMMITTEE ON HUD-INDEPENDENT AGENCIES,
COMMITTEE ON APPROPRIATIONS,
Washington, DC.

The subcommittee met at 10:05 a.m. in room SD–124, Dirksen Senate Office Building, Hon. William Proxmire (chairman) presiding.

Present: Senators Proxmire, Garn, and Grassley.

NONDEPARTMENTAL WITNESSES

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OPENING REMARKS

Senator PROXMIRE. The subcommittee will come to order. Today we will hear from a number of distinguished scientists regarding the administration's plans for the construction of a $15 billion space station.

As the newly elected chairman of this subcommittee, I have been struck by the fact that the proposed station has gone forward without a thorough examination through the hearing process or alternative approaches.

We have tended to rely upon the National Aeronautics and Space Administration for the guidance on the space station issue. This is a mistake for a number of reasons.

First, NASA's primary operating principle is to keep its bureaucracy up and running. This means that the criterion used in judging the value of a project is whether or not it will provide enough work to keep all of NASA's eight centers operating at full capacity.

This criterion was met by the space shuttle program and it will be fulfilled by the proposed space station. However, this big project approach may not always coincide with what is best for the nation's space program, any more than a policy by any industry to keep all of its factories operating regardless of cost or demand would be the best approach for American business.

Second, there is a tendency for all projects of this magnitude to assume a life of their own once the aerospace industry and NASA have invested a substantial amount of money in a particular approach.

To take the space station as an example, despite a doubling of the projected cost of the station, NASA is proposing to pursue the initial design but to cut costs by stretching it out into two phases.

Any discussion of an incremental approach to the station starting with a modest man-tended option or a significant redesign of the station is met with the assertion that any change at this point would jeopardize the entire concept.

Third, this nation's space program has been on hold since the *Challenger* disaster in January 1986 and will undoubtedly continue to be badly crippled through the end of next year.

Part of the blame has to be placed squarely on Congress for relying too heavily on NASA's promises regarding shuttle performance and for going along with NASA's decision to phase out expendable launchers. We would have been better served by receiving more outside advice.

For all of these reasons, we have decided that we should hear from the non-NASA, nonaerospace community before we make an irrevocable decision to proceed with NASA's space station concept.

HEARING PROCEDURE

Today we will take testimony from a number of space scientists and on May 12 we hope to hear from the industrial user community.

I intend to proceed today by breaking the hearing up into two panels followed with testimony from the General Accounting Office on Information technology problems associated with the station as proposed.

PANEL NO. 1

Our first panel will consist of Dr. Carl Sagan, professor of astronomy at Cornell; Dr. James Van Allen, Carver professor of physics emeritus at the University of Iowa; Dr. Riccardo Giacconi, director of the Space Telescope Institute; and Dr. Dennis Smith, professor of biology at Purdue University.

We will hear from each witness and then ask them questions as a panel.

PANEL NO. 2

Our second panel will be composed of Dr. Bruce Murray, a professor at Cal Tech and former director of the Jet Propulsion Laboratory; Dr. Peter Banks, director of the Star Laboratory at Stanford University and former chairman of the Task Force on the Scientific Utilization of the Space Station; and Dr. David Black, NASA's chief space station scientist, who will be testifying on his own behalf.

Finally, we will hear from the General Accounting Office regarding the information technology aspects of situation.

STATEMENT OF SENATOR D'AMATO

Senator D'Amato, who has had an ongoing interest in the space program, is unable to be with us today and has requested that his statement be made a part of the hearing record. Without objection, it will be so ordered.

[The statement follows:]

STATEMENT OF SENATOR D'AMATO

Mr. Chairman, I am pleased to join you for this hearing on the proposed space station. NASA has been proceeding with the development of a permanently manned space station since President Reagan first called for such a program in January 1984. The proposed station will serve both scientific and technical purposes and is to be built as an international venture with European, Japanese, and Canadian participation. It has the potential to become an orbiting laboratory for the conduct of major scientific experiments in microgravity sciences, life sciences, Earth observations, and astronomy. The space station would also be a logical stepping stone for a future manned mission to Mars. Perhaps, most important, the space station symbolizes this nation's commitment to continued leadership in space.

Debate has arisen, however, regarding the costs and benefits of proceeding with the space station as currently envisioned. This debate has focused upon the potential strain that the space station program could place on NASA's resources, endangering progress in its other space research programs. A serious gap has occurred in the launching of scientific payloads following the *Challenger* disaster; it has been suggested that a second gap will ensue during the early 1990's, when two-thirds of the shuttle missions will be devoted to construction of the space station.

This potential dilemma must be resolved, but not at the cost of allowing development of the space station to fall behind. NASA has already examined the possibility of using expendable launch vehicles as an extra launch capability in addition to the shuttle. I am very interested in learning about NASA's current plans for the use of these ELV's. In addition, I am interested in NASA's plans for the use of a heavy-lift launch vehicle in the construction of the space station.

Mr. Chairman, we need to address these issues expeditiously. Prompt development of the space station is crucial. Experience has clearly shown that it will provide our nation with both immediate technological benefits and long-run economic opportunity.

Thank you, Mr. Chairman.

PREPARED STATEMENTS

Senator PROXMIRE. Dr. George Field of the Harvard-Smithsonian Center for astrophysics has submitted a written statement and copies are available for those interested. Dr. Fields was unable to be with us today. In addition, we have also received a written statement from the NASA Alumni League. Both statements will be inserted in the hearing record at this point:

[The statements follow:]

STATEMENT OF GEORGE FIELD, HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS

Mr. Chairman, I am grateful for the opportunity to submit a written statement on the Space Station, although I am unable to testify in person.

The national space program is in serious trouble. We thought that the Shuttle would provide routine access to space, but now realize that it is a test vehicle whose routine operation – even after redesign of the booster – is not assured. The science and applications program meant to fly in the Shuttle is backed up two or three years. The ELV's required to give assured access to space while the Shuttle is being repaired have not been provided for.

On the other hand, the 1986 National Commission on Space, of which I was a member, has recommended that America undertake a major new commitment to begin the human settlement of the Moon and planets. The Space Station is a vital step in this long-term program, serving to test the ability of humans to operate effectively for years under low gravity, or else to develop the means (presumably artificial g) to give us that ability.

A vast abyss separates reality from our dreams. In the words of Andy Stofan, Associate Administrator for the Space Station, "It's a damn shame we're all caught in this situation, but there's no quick way out of it." To come to grips with the situation, the Congress should do two things before making commitments to major new facilities. First, Congress must answer the question implicit in the Commission's report: "What *are* our long-range objectives in space?" Once objectives are accepted, Congress should prioritize every program on the basis of whether it serves the long-range objectives. If the Congress does not do these things, very serious mistakes may lie ahead. We cannot afford another mistake such as the one we made when we allowed the Shuttle to become our only vehicle for routine operations. If the Committee accepts this reasoning, commitment to the Space Station should be made in the context of long-range objectives.

What should our objectives be? On the one hand, Dr. James Van Allen proposes to severely reduce our efforts in the manned space program, while on the other, some advocate a crash program to send a human to Mars before the Soviets do so. The proposals by the National Commission on Space are in between these extremes. The very diverse group of individuals on the Commission – representing everything from astronomy to aeronautics – agreed that human exploration of Mars should be adopted as a *long-range* goal in order to sort out all the other things we want to do in space, including science, technology, enterprise, and development of resources. We concluded that no other goal would have been as scientifically rewarding, as technologically demanding, and as challenging to the American pioneer spirit.

The Commission did *not* recommend a crash program to go to Mars, but rather an orderly program in which technology would be developed and tested in Earth orbit, lunar resources would be searched for and utilized, and space ports would be established in Earth, lunar, solar, and Martian orbits. Such a program would open up tremendous opportunities for new science.

Congress should decide soon whether to accept the Commission's conclusions. If it does not accept these conclusions, Congress must find a mechanism to identify better objectives, and do it soon.

I am not aware that either Congress or the Executive has accepted the Commission's conclusions. As they are the only proposals available from a national body chartered by Congress and appointed by the President, the rest of my discussion is based on the explicit assumption that the Commission's goals will, in reality, become those of Congress.

It seems obvious that new technology should be developed only to serve established goals. As the Commission pointed out, there is an orderly sequence of steps required to begin human exploration of the solar system. It is foolish to pursue these steps in other than a rational sequence.

There is an additional point for which I am obliged to my colleagues participating in the Space Science Board study, *Major Directions in Space Science, 1995-2015*. Historically, carrying out scientific research has provided challenging short-term goals toward which the development of space technology is most usefully directed. In future decades this will be as true as ever, as new propulsion systems, robotics, artificial intelligence, and structural materials are required. An optimum space program will harness space technology to carry out long-term objectives, and shape it to provide key scientific capabilities as it does so.

The salient facts about our space program are that the manned space transportation system is in the garage for repairs, there is virtually no unmanned space transportation system, major scientific missions are ready to go or about to become so, the program of advanced technology development has been recently enhanced and the President has endorsed a space station. In addition, there is a precious core of experienced university, federal, and industrial scientists and engineers and managers available who, if they are not given challenging work, will rapidly lose their edge.

I recommend that Congress establish by law our long-range objectives in space and then prioritize the NASA program in accordance with these objectives, as described above. If Congress accepts the objectives recommended by the Commission, I would offer for discussion this list of priorities:

1. Repair the Shuttle;
2. Provide enough ELV's to get the backlog of science and applications missions into orbit;
3. Initiate a Space Station program focused particularly on testing human ability to operate for long durations under low gravity;
4. Begin to develop the systems necessary for the Planetary Transportation System of the future.

My recommendation on the Space Station is based on the fact that qualification for long-duration human flight is a crucial step in reaching the Commission's goals, and one that must be taken before any other steps into the solar system make sense. As far as I know, only a Space Station has the capability to do this.

Many other uses of the Space Station have been proposed, doubtless so as to obtain the support of as many communities as possible, including scientists, industrial contractors, and overseas collaborators. These uses include, among others, space manufacturing, growth of plants in microgravity, and the servicing of satellites in low earth orbit. Such matters should take lower priority at present for reasons such as the following: space manufacturing will remain a dubious enterprise until basic research on materials in microgravity demonstrates its value; satellites can be serviced by the Shuttle; and we don't need the plants in space yet.

Given this view of the Space Station, it should be possible to configure it so as to meet the limited goals I have stated. Such a Station would cost less than the program proposed by NASA.

Please bear in mind that my recommendation is based on the assumption that you share the Commission's long-range goals for NASA. Obviously, if you do not, the role of the Space Station will be different. For example, if you agree with Dr. Van Allen,

you may decide to cancel the Space Station altogether. If you are convinced that space manufacturing is vitally important now, you may emphasize that requirement.

But there is no escape from the fact that your judgement on the Space Station will be a wise one *only* if you decide what our long-range objectives in space should be.

Professor George B. Field is the Robert Wheeler Willson Professor of Applied Astronmy at Harvard and a Senior Physicist at the Smithsonian Astrophysical Observatory. He has taught at Princeton University, at the University of California-Berkeley, and, as a visiting professor, at Cal Tech. He served as Director of The Harvard-Smithsonian Center for Astrophysics from 1973-1982. A Fellow of the American Physical Society, he is a recipient of NASA's Medal for Exceptional Public Service, as well as the Certificate of Award for Exceptional Services and the Joseph Henry Medal, both of the Smithsonian Institution. He is a member of the American Astronomical Society, AAAS, Astronomical Society of the Pacific, and the International Astronomical Union.

He is the co-author of *The Invisible Universe* and *Cosmic Evolution: An Introduction to Astronomy*, co-editor of *The Redshift Controversy* and *The Dusty Universe*, and is on the editorial council of *Annals of Physics*. His research is concerned with the dynamics of interstellar and intergalactic matter, including galaxy and star formation, the behavior of magnetic fields in space and the astrophysical implications of cosmic strings. Professor Field has served on numerous advisory committees for NASA and the National Academy of Sciences, chairing the Astronomy Survey Committee 1979-1981; he served in 1985 and 1986 on the President's National Commission on Space. He also serves on the NAS/NRC Space Science Board Committee on Major Directions in Space Science, 1995-2105.

STATEMENT OF GERALD D. GRIFFIN, PRESIDENT, NASA ALUMNI LEAGUE

Mr. Chairman and Members of the Subcommittee:

I am Gerald D. Griffin, President of the NASA Alumni League. The League, a 501(c)(3) organization, was chartered last year in the wake of the Challenger accident, by a number of former NASA employees who felt that a vehicle should be created for former employees to support the goals and objectives of aeronautical and civil space programs set forth in the National Aeronautical and Space Act of 1958. Membership in the League is open to all former NASA employees. Our membership presently totals less than 300, but we expect to continue to grow in the years ahead. I should add that we are in no way affiliated with or beholden to NASA. Thus, while we will probably frequently agree with NASA program goals, our basic allegiance is to the NASA Act, not the NASA organization or program at any given time.

We appreciate very much your willingness to accept this testimony, Mr. Chairman. It is the first that a League officer has presented to any Committee of the Congress.

As President of the NASA Alumni League, I strongly support the Space Station program and urge the Committee on Appropriations to endorse once again the concept of a permanently manned United States civil presence in space by providing the funds requested this year to proceed with hardware development.

The Space Station is an extremely important national undertaking. It represents a commitment to the future at a time when of necessity NASA must spend considerable time and energy reshaping current programs and policies. It represents a determination on the part of the United States to accept the Soviet challenge in space and to regain a position of leadership. It also represents the kind of work that NASA is best at. NASA is charged with the conduct of space science and the development of new technologies. Its job is to push back the frontiers of knowledge and to bring home to Earth the benefits that can be obtained by using the unique environment of space. The space Station is a project that will do just that. It will require NASA to do the work it is trained for and at which it excels.

The erosion we see of U.S. leadership in space is dismaying. In the past decade, European, Japanese and Soviet space programs have matured to a point where they match our own. Technically they are quite sound. Programmatically they are broad and ambitious, having developed launch vehicles, spacecraft and the infrastructure necessary to successful space endeavors. Our own space program has not kept pace. While we have accomplished a number of notable achievements in the last ten years, the scope of our activities has fallen short. We need to realize that past accomplishments, however memorable and rewarding, do not assure continued leadership. Apollo, Viking and Voyager were triumphant missions but they were many years ago. We need to take a lesson from the painful experience of many segments of American industry. The future belongs to those who plan and invest, and who take the competition seriously. Space can continue to be an American success story. But the President and the Congress must give NASA the mandate and funds necessary to do the job. We are confident that NASA, with programs such as the Space Station, can accept today's challenges and restore America's pre-eminence in space.

Since President Reagan charged NASA in 1984 to develop the Space Station, the agency has made substantial progress in putting together a program and conducting the initial analyses. As alumni we are not familiar with the details of the Space Station program. But our understanding is that a comprehensive Phase B study of the Space Station was conducted by NASA and industry. Our experience tells us that such extensive preliminary analyses is the correct approach. Thorough analysis before proceeding to hardware development is the best way to assure that cost and schedule targets are met.

While the Space Station endeavor is making substantial progress, we are concerned about certain aspects of the program. A major concern is program pace.

At a time when the development activity should be moving ahead smartly, the pace appears indecisive and without the momentum it should have. The RFP's have only been just released. The Administration, despite the President's clear directive to establish a Space Station "within a decade" is projecting a budget that realizes a permanently manned configuration in 1996.

Let's direct NASA to get on with the job. Let's give NASA the resources to develop the Space Station and allow the agency to move ahead. The United States needs the Space Station and we should develop it without further delay.

Thank you, Mr. Chairman.

OPENING STATEMENT OF SENATOR GARN

Senator PROXMIRE. I am happy to yield to my distinguished colleague, who is not only a member of this committee and a fine U.S. Senator and a great former chairman of the Banking Committee, but he is also an astronaut in his own right, and he has studied the space situation more than any other Member of Congress.

Senator Garn?

Senator GARN. Thank you, Mr. Chairman. I had not intended to make an opening statement but, in response to yours, I feel compelled to make a few comments.

I don't necessarily disagree with what you have said as far as some of the criticisms. There is no doubt that some of them are accurate. The difficulties over a space station have gone on for some time. I would just make a couple of comments that it has not gone on without some scrutiny.

There have been changes. Almost 3 years ago, Congressman Boland and I, your counterpart now as chairman of the House committee, held up NASA funds for a period of several months because we did not feel that the balance between robotics and science versus a man-tended station was sufficient, and that NASA was going too much in the direction of a simple man-tended station, and we thought we ought to be pushing the frontiers of science.

So, there was restudy and reports from Administrator Beggs, at that time, so it isn't fair to say that there has been no scrutiny or no consideration during the process of trying to design a space station.

I would say that most of your criticism on these problems should be directed at two places, though, and not at NASA; at Congress and the administration, and more particularly the Office of Management and Budget.

As you have said, I have been rather close to the program and what you will find is that—I am getting all choked up talking about OMB. [Laughter.]

LACK OF VISION AT OMB

If you look, NASA officials both past and present were able to testify as to what they would really like to do, rather than how they come here and testify after OMB has dictated. I mentioned the bean counters over at OMB, who have no vision of the future in any program of the United States government. As far as I am concerned, they are the old green eyeshade, black armband accountant-types, who don't understand much in the way of policy or what can be gained for every man, woman, and child on the face of this Earth from space-derived technology and scientific achievements to be learned from space exploration and travel.

There is no doubt that that is true. I am not going to take the time to go into a lot of other examples of why we didn't have a probe up to Halley's Comet. I was embarrassed that Dr. Sagan had to go to the Soviet Union to be cooperative with them in observing that; that we did not have our own probe up there.

BUDGETARY CONSTRAINTS

You will find that what NASA would like to have done over the years has largely been limited by this Congress and by OMB for budgetary constraints. I am not saying that it isn't important that we play a part in the solution to the budgetary problems of this country, but on the other hand, when you consider that over the last decade we have only spent about one-half on space exploration and travel, either manned or unmanned, what we spend on food stamps in this country every year.

I am not opposed to food stamps, I just put it into perspective. We have had a very, very small national effort in terms of space; less than about one-half of 1 percent of the total budget of this country. So when we get critical of what we are doing and where we are going and what our vision of the country is, let's look at the bean counters and not most of the scientists who have had much more ambitious plans and programs and desires for what they would like to accomplish for this country.

CONGRESS FAULTED

Once again, Mr. Chairman, although I agree with many of your criticisms, I think we ought to direct that criticism where the fault really lies: here in Congress with a lot of people, both in the House and the Senate, who have no comprehension of what science or space is all about.

I would amplify that, not only to space science, but we haven't done nearly as good a job as we should for the National Science Foundation. It has been underfunded. We don't have enough science teachers in this country in the secondary schools, the junior highs, and high schools of this country. We don't train them adequately.

A couple of years ago, in my son's high school, I was at back-to-school night, and it was interesting that the teacher, even though it had been 30 years since I had had any chemistry, didn't seem to be adequately prepared.

Afterward, as I was talking about my son's performance, he said, "I apologize, I am not a chemistry teacher, I am a math teacher, and I am just reading a few chapters ahead of the students." So in the whole area of science, we have been so enamored with appropriating money in this Congress for immediate gratification for people and things that give us credit by the next election than looking at the longer range, when we have to look at 10 or 15 or 20 years down the road, and that is where cutbacks in science hurt.

We don't notice the difference before the next election or the one after that, or the one even 5 years down the road. Where we are suffering for lack of expenditures in scientific achievement in this country was done 10 or 12 or 15 years ago. When OMB is shortsighted now, and when Congress is shortsighted now, we are not going to find out about it before we face reelection. But, some future Congress and some future President is going to suffer around the year 2000 because we didn't have the foresight to properly fund scientific research and development in this country.

Once again, your criticisms are accurate in many respects, but the blame lies here, and it lies down at the bean counters of OMB, not with the scientists who have a much greater vision of the future than we do.

Thank you, Mr. Chairman.

Senator PROXMIRE. Thank you, Senator Garn.

Senator Grassley?

REMARKS OF SENATOR GRASSLEY

Senator GRASSLEY. Mr. Chairman, I am going to submit some questions for Dr. Van Allen, and submit a statement as well, because I want to explain that I am dividing my time between here and the full Appropriations Committee, which you know is meeting.

I want to say in regard to my constituent, the famous Dr. Van Allen, that we are proud to have him here today for this testimony. More importantly, it doesn't take a Senator like me to add to the tributes that have already been given to him, so I am not going to attempt to do that.

I am going to say, though, that the state as well as myself, as one of the public officials of the state of Iowa, are very proud of Dr. Van Allen's pioneering work in space as well as his contribution to this current subject that we are dealing with here today.

So, I thank you, Mr. Chairman, for inviting him, and if I am not here at the time of questioning, then I would ask that you would submit my questions for answer in writing.

Senator PROXMIRE. They certainly will be.

Thank you very much, Senator Grassley.

I would like to say to the panels that the reason there aren't more members of the subcommittee present is because, as Senator Grassley has said, we are having a markup, a very important markup of a supplemental appropriation.

Senator Garn and I are both torn. We would like to be there. We have a responsibility to be there, but we also feel very strongly about this hearing this morning.

Otherwise, I am sure there would be other Senators present. Thank you very much.

PANEL NO. 1

STATEMENT OF CARL SAGAN, PROFESSOR OF ASTRONOMY, CORNELL UNIVERSITY

Senator PROXMIRE. Dr. Sagan, we are delighted to have you here.

Dr. Van Allen, Dr. Smith, and Dr. Giacconi, won't you join Dr. Sagan at the witness table.

Dr. Sagan, you go ahead, and then we will hear from the other three members of the panel.

Dr. SAGAN. Thank you, Senator Proxmire.

If I may, I would like to submit for the printed record a statement entitled, "A Space Station Worth the Cost," by Bruce Murray, Louis Friedman, and myself.

Senator PROXMIRE. Without objection, that will be printed in its full form.

Dr. SAGAN. Thank you.

GOAL NECESSARY

More than money, more than launch vehicles, and more than a space station, NASA needs a goal. The tragedy of *Challenger* dramatized that sending people into space is dangerous as well as expensive. To justify risking lives and money, the purposes of space flight with human crews must be clearly stated and found worthy.

I was a member of the OTA panel on civilian space stations and America's future in space. We had the following continuing and frustrating experience with NASA officials called to testify. They would give a long list of things you could do in space, if you had a space station in orbit, and we would say, "That is well and good, but could you please tell us what NASA's goals in space are and then we can try to make an assessment of whether a space station is the best way to go after some of those goals."

NASA was wholly unwilling to do that. The reason being that there is no NASA goal in space, no coherent statement of what NASA's purpose in space is since the decline of the Apollo era.

The space station itself is imagined vaguely as a stepping stone to something, although no evidence is offered to show that it is in fact such a stepping stone. I might mention, Mr. Chairman, recent testimony by John Andolin of OTA, before the House Committee on Science, Space and Technology, dated March 31, 1987, in which he attempts to update the OTA's view of the matter, saying that the insides of the OTA report of a year or two ago are still valid.

MICROGRAVITY RATIONALE

The principle NASA justification for the space station in its present configuration seems to be a kind of microgravity rationale, the vague notion that space holds great potential for manufacturing of pharmaceuticals, alloys, ball bearings, and the like.

Yet, outside of the aerospace industry itself, and beyond verbiage, no large commercial concern shares this space station goal strongly enough to share the costs of its development. No one has offered compelling arguments that space industrialization would be economically competitive with manufacturing on Earth when a comparable capital investment is made.

Nevertheless, the key and often unstated assumption that products manufactured in space can be commercially profitable continues to permeate U.S. space station planning. The issue is important because to a significant degree the design of the space station is to optimize microgravity processing.

There is certainly nothing wrong with microgravity research, but to have microgravity processing be the main focus and driver of the space station to the extent it is seems to be a mistake. The only identified interests, foreign or domestic, with a serious commitment to the station, are the organizations that stand to profit from building it.

Japan and Western Europe are willing, for political and space technology reasons, to pay for 5 or 10 percent of development costs, but where is the participation in the space station of AT&T, say, or IBM, or General Electric, or Texas Instruments, or Johnson & Johnson, or their foreign counterparts?

The unwillingness of such firms to invest significant capital funds is a clear indication that a coherent commercial justification for the space station has not been made. If it hasn't been made, it certainly seems worthwhile to ask why is a project of this degree of not only cost, but risk, being oriented so strongly toward an objective whose justification has not been made?

EXPLORATION OF MARS

I would like to suggest that there are coherent long-term goals for NASA and for the space station that have ecumenical support that can have benign long-term positive value for the future of NASA, and that the principle such goal, the most effective such goal, is the prospect of human exploration of Mars.

It is remarkable for the diversity of opinions that it embraces. Among other reasons, it is justified as a human adventure of high order, able to excite and inspire the most promising young people, and to convey that high technology can be consistent with a hopeful future. As a potential scientific bonanza, for example on climatic change, on the search for present or past life, on the understanding of an enigmatic martian land forms, and on the application of new knowledge to our own planet.

It is also an aperture to an international prestige and technological development. It is, I think, an extremely important aspect of it, a realistic and possibly unique opportunity for the United States and the Soviet Union to work together, and with other nations, in the spotlight of world public opinion and on behalf, for a change, of the human species.

Finally, such a morass goal is justified as an in-depth exploration of the only other planet that may some day sustain human life. If we start soon on a long-term program to investigate Mars, culminating with humans landing on this planet some time in the first quarter of the next century, we can revive a dispirited NASA. We can provide it with a focus and a sense of purpose on an appropriate time scale and establish a standard by which to judge proposed major NASA activities, and their subsequent progress.

The NASA space station as now envisioned is not a practical stepping stone to Mars. With it we would learn little of the effects of long duration space flight on humans, particularly on spinning large structures to produce artificial gravity, and this is very likely something our species will have to understand before setting out to Mars. Nor, will the present space station configuration enable us to assemble propulsion stages in orbit and build the ships that will some day take us to other worlds.

To conclude, I believe that NASA should reconsider the space station design. Its new focus instead should provide a more mature definition of the station requirements, consideration of how to support the goal of landing humans on Mars, and a critical assessment of the prospect of spending tens of billions of dollars in the short term to permit extremely dubious space manufacturing endeavors some time in the next century.

Most important, taking more time in defining the space station will permit now budgeted resources to go into fixing the shuttle, into buying expendable launch vehicles, and to prompt implementation of important science and applications programs that are now languishing.

The aim is neither a smaller nor a larger NASA budget, nor is it a smaller or larger manned program. Instead, we advocate a NASA budget and a manned space flight program that are worth the cost and risk. The only way to measure that worth is to establish a coherent long-term NASA goal.

We urge the President and the Congress to commit the United States now to join with all other spacefaring nations in preparing to send explorers to Mars early in the next century. Human exploration of Mars at the beginning of new millenium is a goal worthy of the promise of the space age and the aspirations of the human species. A space station designed to help implement that goal would be well worth the cost.

Thank you, Mr. Chairman.

Senator PROXMIRE. Thank you, Dr. Sagan. I especially want to thank you for stating your case so well, and so concisely. I neglected to request, because of the fact that we have a number of witnesses this morning, that the opening statements be as concise as possible and you certainly met that standard very well without any suggestion from the chair.

In addition, Senator D'Amato, who is unable to be present, has requested your response to several queries which I will submit to you on his behalf.

[The statement and correspondence follow:]

LETTER FROM CARL SAGAN, BRUCE MURRAY, AND LOUIS FRIEDMAN

23 JULY 1987.

Senator WILLIAM PROXMIRE,
U.S. Senate,
Dirksen Senate Office Building,
Washington, DC.

DEAR SENATOR PROXMIRE: We are pleased to respond to your letter of May 4, 1987, relaying Senator D'Amato's queries about the utility of the currently proposed space station configuration for assembly of propulsion stages in Earth orbit. This is a vital capability for the U.S. space program and the absence of such a capability in the present space station plan will put the country at a significant disadvantage in the 1990's.

The Committee is aware of the present limitations on U.S. capability to lift heavy payloads. With our present plans, we cannot expect a capability of putting more than 22,000 kilograms [kg] into low Earth orbit [LEO] for at least 10 years. (For comparison, the new Soviet Energia booster can lift some 100,000 kg of payload into LEO.) While this is sufficient for many LEO applications, it is inadequate for geosynchronous orbit

or interplanetary applications. The large propulsion requirements to reach these higher orbits and greater speeds mean that only approximately 5,000 kg could be put in geosynchronous orbit or to Mars. These are crying contraints if the nation is interested in a robust space program.

For example, a large communications satellite in geosynchronous orbit—containing large antennas for advanced communications, navigation, search and rescue, et cetera—is estimated to require a mass of 20,000 kg. A remote sensing satellite able to take images and make observations of the Earth sufficient for our needs of scientific study, national security, arms control, land use, global environmental modeling, et cetera, has been estimated to require a mass in geosynchronous orbit in excess of 5,000 kg. A Mars sample return mission, of the type long advocated by the National Academy of Sciences' Space Science Board, and other groups as the next major step in U.S. planetary exploration (and now being studied both in the United States program and for possible international cooperation with the Soviet Union), would require a mass of 11,000 kg in LEO. It is clear from these examples that we need the capability for larger masses in low-Earth orbit even for missions we would like to be able to consider now.

For many years the capability for in-orbit assembly—that is, the assembly of stages and spacecraft in Earth orbit—has been studied and considered in NASA, mostly at the Johnson Space Center. It has generally been viewed as a technology within our capability and not requiring excessive costs or technical advances to carry out reliably. It is also recognized as a capability that will be required in the future no matter what other launch vehicle decisions are made. With all the consideration made of in-orbit assembly capability in the late 1970's and early 1980's, it is surprising to find this not being considered for the space station. The reason is that the space station is being driven by other requirements inconsistent with in-orbit assembly. Specifically, the severe demands of creating and maintaining a microgravity environment for the operational development of microgravity processing (aiming at allegedly self-supporting space industrialization) are inconsistent with the disturbance torques that would be generated by vehicle assembly and staging. NASA tells us that this can be overcome by a separate facility, physically distinct from the basic space station. But this simply means building another, quite different space station. If the regular operational need for a microgravity processing facility were well-founded, if the very high priority now being accorded to it were justified, then the situation might be acceptable. However, for all the reasons explained in our testimony and in the statements of other experts, having the microgravity processing requirement prohibit the development of on-orbit assembly is, we believe, a serious error in priority assessment.

The capability for in-orbit assembly can be met with reasonable budget and schedule restraints—unless it is ignored completely in the current space station activity. A broad exploratory goal for NASA, particularly, human exploration of Mars, could be used to pace the development of this important capability—as well as the equally important scientific and engineering studies required for long-duration human flight and advances in life sciences, and valid microgravity research in the space station, so that progress could be made in all these areas through the 1990's. The alternate, present course will find the nation once again with all of its eggs in a poorly woven and expensive basket.

Cordially,

CARL SAGAN,
BRUCE MURRAY,
LOUIS FRIEDMAN.

STATEMENT OF CARL SAGAN, PROFESSOR OF ASTRONOMY, CORNELL UNIVERSITY

A SPACE STATION WORTH THE COST:

THE PLANETARY SOCIETY PROPOSAL

CARL SAGAN BRUCE MURRAY LOUIS FRIEDMAN

Dr. Sagan is David Duncan Professor of Astronomy and Space Sciences and Director, Laboratory for Planetary Studies, Cornell University. Dr. Murray, former Director of NASA's Jet Propulsion Laboratory (JPL), is Professor of Planetary Sciences, California Institute of Technology. Dr. Friedman is former Manager of Advanced Studies at JPL. They are, respectively, President, Vice President, and Executive Director of The Planetary Society, the largest space-interest group in the world.

More than money, more than launch vehicles and more than a space station, NASA needs a goal. The tragedy of Challenger dramatized that sending people into space is dangerous as well as expensive. To justify risking lives and money, the purposes of spaceflight with human crews must be clearly stated and found worthy. Voyages to explore our neighboring planet, Mars, constitutes such a worthy, long-term goal--and, we believe, an optimal goal.

The prospect of human exploration of Mars is ecumenical--remarkable for the diversity of opinion it embraces. It is justified among other reasons:

--As a human adventure of high order, able to excite and inspire the most promising young people, and to convey that high technology can be consistent with a hopeful future.
--As a potential scientific bonanza--for example, on climatic change, on the search for present or past life, on the understanding of enigmatic Martian landforms and on the application of new knowledge to our own planet.
--As an aperture to enhanced national prestige and technological development.
--As a realistic and possibly unique opportunity for the United States and the Soviet Union to work together, and with other nations, in the spotlight of world public opinion on behalf of the human species.
--As an in-depth exploration of the only other planet that may someday sustain human life.

If we start soon on a long-term program to investigate Mars, culminating with humans landing on the Red Planet sometime in the first quarter of the next century, we can: revive a dispirited NASA; provide it with a focus and sense of purpose on an appropriate timescale; and establish a standard by which to judge proposed major NASA activities and their subsequent progress.

But NASA's space station, as now envisioned, is not a practical stepping stone to Mars. With it, we would learn little of the effects of long-duration spaceflight on humans--something our species will have to understand before setting out for Mars. Nor will it enable us to assemble propulsion stages in orbit and build the ships that will take us to other worlds.

THE MICROGRAVITY RATIONALE

Instead, the rationale behind the now $20 billion space station rests largely on the vague notion that space holds great potential for manufacturing--of pharmaceuticals, alloys, ball-bearings and the like. Yet outside the aerospace industry itself and, beyond verbiage, no large commercial concern advocates the space station strongly enough to share the costs of its development. No one has offered compelling arguments that space industrialization would be economically competitive with manufacturing on Earth when a comparable capital investment is made. Nevertheless, the key and often-unstated assumption that products manufactured in space can be commercially profitable continues to permeate US space station planning.

In particular, a severe microgravity requirement has been levied on the current station design to permit development of microgravity processing. This introduces at least three inconsistencies: First, the priority on microgravity processing precludes emphasis on other needed developments, such as in-orbit rocket assembly, life-science research in variable gravity, and very-long-duration human flight. Second, it dictates a set of demanding and expensive requirements solely to maintain the large microgravity capability and to provide high power levels for its operation. Third, microgravity is intrinsically incompatible with a human presence; such experiments are better done in dedicated recoverable or revisitable automated facilities.

Some assert that a microgravity capability is important for American competitiveness in the world market. But by investing precious dollars in an uneconomic space facility, US competitiveness in space applications will go the way of its once undisputed competitiveness in launch vehicles. Others argue that international agreements based on anticipated commercial benefits have already been negotiated and therefore must be followed through. Does this mean that there is a set of foreign industries poised to profit from the station? No. The only identified interests, foreign or domestic, with a serious commitment to the station are the organizations that stand to profit from building it. Japan and Western Europe are willing, for political and space technology reasons, to pay for five to ten percent of the development costs. But where is the participation in the space station of AT&T, IBM, GE, Texas Instruments, Johnson & Johnson, or their foreign counterparts? Their unwillingness to invest significant capital funds is a clear indication that a coherent commercial justification for the space station has not been made.

In a letter to Secretary of State Schultz, Secretary of Defense Weinberger has expressed a "national" security interest in the space station, although DOD has yet to offer to help with the funding. A quasi-military space station built by a civilian space agency would profoundly conflict with the 1958 National Space Act and with the NASA Charter. (However, as a result of negotiations mediated by the National Security Council, military applications will now be played down.) In contrast, a space station that would enable planetary exploration is fundamental to and consistent with NASA's Congressional mandate.

MARS AND LONG-DURATION HUMAN FLIGHT

The task of sending humans to explore the solar system--particularly Mars--has been largely ignored by NASA since the

death of Wernher von Braun. It certainly has not been a significant factor in the current design of the space station. Yet NASA's own Advisory Council has recommended that the agency adopt the goal of Mars, as did the President's National Commission on Space. The goal of Mars has been endorsed in many recent editorials in major newspapers, including seven in the New York Times, and others in the Los Angeles Times, the Christian Science Monitor, the Denver Post, and the Washington Times. The Mars goal has also been endorsed in a congressional resolution initiated by Sen. Spark Matsunaga and cosponsored by Sen. William Proxmire, among others. It has been publicly supported by many other members of Congress.

The Planetary Society has witnessed another sort of endorsement of Mars exploration. Our members, a broad cross-section of 100,000 American citizens, voted for Mars in a very real way--by donating, bit by bit, over $200,000 to enable the Society to advance the prospect of humans on Mars.

Even so, no requirements for Mars exploration have been seriously considered for the space station. Despite repeated rhetorical references by NASA officials to the proposed station's relevance for interplanetary flight, the technical specifications and planned capabilities do not address planetary exploration.

Perhaps only modest changes in the present program would be sufficient to provide the crucial knowledge we need to send humans to Mars. Or perhaps not. No one really knows because NASA has never seriously studied the necessary requirements. Key questions must be answered:

- Will the space station provide crucial data about:
  - --Supporting human life in space for long periods?
  - --The competing effects on crews of artificial (spinning) gravity, versus adapting to zero-gravity?
  - --The necessary scale of life-support systems for interplanetary flight?
  - --Closed ecological systems?
  - --Deep-space radiation hazards to humans, including solar flares and the utility of spacebased proton shelters?

- Will the space station provide the experience we need to design interplanetary vehicles, particularly:
  - --Launch vehicles?
  - --Orbital transfer vehicles?
  - --Assembling propulsion stages in orbit?

- Will the space station satisfy requirements for:
  - --Quarantine of samples returned from Mars?
  - --Possible coordination with the Soviet Mars program?

Our examination of NASA's planned space station forces us to conclude that these questions must be answered, for the most part, in the negative.

For example, engineers continue to debate the benefits of "weightlessness" vs. artificial gravity on flights between the planets--but these arguments are based mainly on faith, not data. From the beginning of manned space flight, most have presumed that human crews can somehow adapt to weightlessness. But the extensive Soviet efforts in zero-gravity long-duration flight seem to have stalemated after reaching an 8-month limit--far short of the time needed for a realistic mission to Mars and back. After such flights, cosmonauts had to be placed in hospitals to recuperate. But there will be no hospitals on Mars. The

space station plan must include a systematic way to acquire the needed comparative data, including tests of humans in large rotating structures in Earth orbit, which would provide artificial gravity.

We also need more ground-based and Earth-orbital research on closed-ecological life-support systems before the space station goes into operation. That research could begin now, on the ground, even while space station requirements are being redefined.

The current space station schedule calls for developing physical structure first, with most *in situ* applications postponed to some indefinite later time. This is a mistake which becomes even more severe in NASA's newly revised two-step plan. We suggest instead a more flexible modular approach, in which some early low-power applications and research could be carried out while facilities for long-range objectives are built up gradually. This would give the United States an earlier return on its investment. The modular, step-by-step approach has served the Soviet Union well, and could also benefit the US.

An obviously desirable function for the US space station will be the capability to assemble large payloads in low orbit, and then to send them on to geosynchronous orbit and interplanetary trajectories. An easy, reliable way of reaching beyond low Earth orbit must be developed soon. However, the current space station plan does not include such a capability or even permit it. This capability is far more important for the United States, and has a much more favorable cost-benefit ratio, than the competing objective of developing a microgravity environment. Maintaining the microgravity requirement requires that there be few disturbances on the space station; such disturbances would be unavoidable while assembling rocket stages.

If the space station is developed to prepare for an expedition to Mars, can it still fit more general needs for space development? The goal of landing humans on the Moon, so successfully met by the Apollo program, also gave us a stable of capable launch vehicles, a small but effective space station (Skylab), a series of successful spacecraft that initiated the golden age of planetary exploration, and advances in space communications, power, propulsion, data processing, computing, materials and life-support capabilities.

An overriding and compelling single-purpose goal, when sufficiently broad and challenging, need not yield be a single-benefit program. If the space station is developed to provide responsible support for a human mission to Mars, it will also advance the United States' abilities to:

--Build structures in space,
--Support life in space,
--Understand low-gravity and vacuum technologies,
--Lower costs and provide reliable access to space,
--Advance aerospace engineering and space science, and
--Explore the solar system.

WHAT'S THE RUSH?

Today, the American space program is in shambles, despite generous funding for many years. The enormous past investment in the shuttle program, plus the large new investments required to restore it even to a minimally operational state, threaten the viability of the entire civilian space program. Funding a space station and timing its construction become critical to everything

else NASA would like to do. How much will it cost? Why build it now? The goal of landing humans on Mars sometime during the first quarter of the next century could provide a coherent and reasonably paced objective against which to match space station development and schedule.

A human mission to Mars will require the United States to develop new expendable launch vehicles (as will anything more than a rudimentary space station), to send precursor robotic missions, to research life support, and to develop life-supporting vehicles. A well-designed national program would address these requirements, and see that they are carried out in parallel and at a reasonable pace, and that they meet the political and economic conditions imposed by the goal of exploring Mars.

It would also allow American space sciences to reverse their present decline. The Space and Earth Science Advisory Committee Task Force on Scientific Uses of the Space Station recently told NASA that the space station should be reevaluated and reformulated or the United States could lose an entire generation of space scientists.

It is impossible to start a responsible space station program until the true payload capability, flight frequency and, especially, cost per pound of cargo for the shuttle have been demonstrated, rather than overoptimistically guessed at--as has been the common NASA practice in the past.

In the early 1990s, NASA must gain genuine experience and maturity in shuttle operations. In parallel it can begin research soon on life support in space by lengthening shuttle missions from a few days to weeks. The shuttle can be used in this way for a broad array of experiments and activities. Many scientists believe that it is more effective to use the shuttle as an experimental facility than as a "space truck." It may prove wiser to let the space station implementation wait for more appropriate expendable launch vehicles to become available, just as the Soviet successes with its Mir space station and other facets of manned space flight are built upon a solid foundation of routine expendable launch vehicle use.

TAKE THE TIME NOW AND DO THE JOB RIGHT

NASA should reconsider the space station design. Its new focus instead should provide (1) a more mature definition of the station requirements, (2) consideration of how to support the goal of landing humans on Mars, and (3) critical assessment of the prospect of spending tens of billions of dollars in the short term to permit extremely dubious space manufacturing endeavors sometime in the next century. Most important, taking more time in defining the space station will permit now-budgeted resources to go into fixing the shuttle, into buying expendable launch vehicles, and into prompt implementation of important science and applications programs that are now languishing. Only then can the United States begin to earn back its place in space.

Our aim is neither a smaller nor a larger NASA budget. Nor is it a smaller or larger manned program. Instead, we advocate a NASA budget and a manned space flight program that <u>are worth the cost and risk</u>. The only way to measure that worth is to establish a coherent long-term NASA goal. We urge the President and the Congress to commit the United States now to join with all other spacefaring nations in preparing to send explorers to Mars early in the next century. Human exploration of Mars at the beginning of the new millennium is a goal worthy of the promise of the space age and the aspirations of the human species. A space station designed to help implement that goal would be well worth the cost.

STATEMENT OF JAMES A. VAN ALLEN, PROFESSOR OF PHYSICS EMERITUS, UNIVERSITY OF IOWA

Senator PROXMIRE. Dr. Van Allen, go right ahead, sir.

Dr. VAN ALLEN. Thank you, Mr. Chairman. I have submitted a brief written statement, which I would appreciate having in the record, if that is agreeable.

It is no news that the space programs of the United States, both civil and military, have been acutely disabled since the *Challenger* accident in January 1986. Billions of dollars worth of high-priority commercial, scientific, and military spacecraft are backing up in the launching queue but, within the civil sector, no effective effort is being made to remedy this disgraceful national situation.

NATIONAL DISABILITY FORESEEN

In fact, the present inflexible policy runs in the opposite direction. That is to worsen the situation. The likelihood of such a national disability was foreseen in testimony before this committee on June 29, 1971, by Senator Walter Mondale, Thomas Gold, Brian O'Leary, and myself. The committee was then chaired by Senator John Pastore.

At that time, advocates of the development of a fleet of manned space shuttles promised the Congress that each of the proposed shuttles would deliver 50,000 pounds of payload into low Earth orbit at a launching cost of $100 per pound; that each shuttle would have a useful lifetime of 100 missions; that by the early 1980's the United States would be conducting 50 shuttle flights per year—that is about one per week—for civil purposes alone; and that all expendable launch vehicles would thereby be rendered obsolete.

Those, I might say, are essentially verbatim and faithful quotations from the testimony presented by advocates of the shuttle in 1971, at which I was present. The outrageous optimism of those promises was described in the above-cited testimony. It is now evident to everyone.

In contrast, the unmanned elements of our space program have consistently delivered on their promises and have usually gone far beyond them. The burden of my testimony this morning is an assault on prevailing national policy for the conduct of our civil space program. A policy that ignores the lessons of experience, emphasizes things that do not work, and neglects the things that do work.

I make this criticism as one who has devoted over 40 years of intensive professional activity to space exploration. There is no one who wishes its continued success more than I do. I recognize that this committee, Mr. Chairman, is concerned with appropriations. But I am not here to suggest that everything I have mentioned above can be fixed by another $1 or $2 billion per year.

POLICY AT FAULT, NOT BUDGET

On the contrary, I consider that the federal budget for civilian space activities is already at a reasonable level and that the primary fault is one of policy and not one of appropriations.

On January 25, 1984, I listened very carefully to President Reagan's State of the Union Address and later got a transcript of it from the Congressional Record. He singled out space exploration as the second of his four great goals for America. That was very pleasant to hear, but I was appalled by his emphasis as represented by the following verbatim excerpt from his address:

> We can follow our dreams to distant stars, living and working in space for peaceful, economic, and scientific gain. Tonight, I am directing NASA to develop a permanently manned space station and to do it within a decade. A space station will permit quantum leaps in our research in science, communications, and in metals and life-saving medicines which can be manufactured only in space.

He continued with remarks on the enormous potential for commerce in space. A year later the President reiterated his enthusiasm for space as "the next frontier" and emphasized the bright prospects for manufacturing exotic medicinals for curing disease and extraordinary crystals for revolutionizing electronics, all in a permanently manned space station.

These statements were so hyperbolic and so ill-founded as to leave an informed person gasping for breath. Indeed they resembled science fiction much more closely than they did sound national policy.

PRINCIPAL ELEMENTS OF 40 YEARS' EXPERIENCE

In refutation of the President's statements, I submit that the principal elements of our 40 years of experience in space are as follows:

First, despite much speculation, only one truly commercial application of space technology has emerged thus far. That is represented by our great global network of communication satellites and the associated industry, including the manufacture of launch vehicles.

In addition, private companies have, of course, the central role in selling space equipment and services to the federal government. But these latter functions do not qualify for the usual understanding of the term "commercialization," which means providing products and/or services that pay their own way in the nongovernmental marketplace.

Second, there are many other important utilitarian applications of space technology: weather observation and forecasting; remote sensing of the Earth's surface resources; marine and aircraft navigation; the applied sciences of the Sun and of the Earth's ionosphere, magnetosphere, atmosphere, and oceans; and military reconnaissance, surveillance, and other applications that are technically similar to those for civil purposes. But all of these applications remain wholly or principally in the area of governmental services.

Third, nearly all of the above-mentioned applications of space technology and nearly all of the spectacular advances in the space sciences, including planetary exploration and space astronomy have been, are being, and will continue to be accomplished by unmanned, automated, commendable spacecraft.

Moreover, most such spacecraft have been and can be launched by expendable launch vehicles and at considerably less cost than by the shuttle, despite the grossly optimistic predictions to the contrary in the early 1970's, and with minimal risk to human life.

Fourth, materials processing in space is still an embryonic science. It has significant research interest but, as of the present date, its demonstrated commercial potential is wildly incommensurate with the cost of a space station that has materials processing as one of its principal declared purposes.

A massive 2-year study entitled "Space Science in the Twenty First Century: Imperatives for Two Decades, 1995–2015," under the auspices of the National Academy of Sciences, has been completed recently. Apart from biomedical research on human subjects, this study has again found few first-order scientific objectives that require human crews in space, much less a permanently manned space station, during the adopted timeframe.

The cost/benefit ratio of secondary purposes such as repair, refurbishment, refueling, and replacement of equipment in Earth orbit is, I think, greatly underestimated by advocates of the space station. Indeed, it is much more cost-effective to improve the reliability and versatility of space equipment by preflight developmental and test work and, if necessary, to service it by remotely controlled, unmanned spacecraft.

The true heavy hitters in space science and applications have been long-lived satellites and spacecraft based on intrinsically good design, good engineering, and rigorous testing. There has been a truly astonishing difference in the responses to the present national emergency in space by the Department of Defense and by the National Aeronautics and Space Administration.

STATEMENT OF AIR FORCE SECRETARY ALDRIDGE

Soon after the *Challenger* accident, Secretary of the Air Force Edward Aldridge made the forthright public statement:

> We made a great mistake in planning exclusive reliance on the shuttle for the delivery of military satellites into space. Believe me, we will not make that mistake again.

True to his word, he placed the Vandenburg shuttle launch facility in caretaker status and immediately initiated the procurement of a family of expendable launch vehicles for defense purposes. This same position has been taken by the National Oceanic and Atmospheric Administration.

But the administration of NASA has steadfastly refused to recognize the full import of the existing problem and chooses to devote the principal part of its resources to the pursuit of vaguely defined objectives of a futuristic nature.

Its 1987 and 1988, budgets emphasize repair of the shuttle system, the procurement of a replacement shuttle, a continuing primary dependence on manned spacecraft for all purposes, and the rapid development of a huge space station.

NO URGENCY FOR SPACE STATION

I grant the political face-saving importance, perhaps even the political necessity, of resuming shuttle flights with improved safety. But there is no urgency to building a replacement shuttle and far less urgency to developing a space station.

The true national urgency, in my view, is to return to primary dependence on expendable launch vehicles for both civil and military purposes. Yet NASA's 1988 budget, now before this committee, makes provision for the purchase of only one ELV.

Three years ago NASA promised the Congress that it could build a large space station for $8 billion over a 10-year period. This estimate, as with the shuttle program estimates in 1971, was so optimistic and so incomplete as to be deceitful, at least to the uninformed. In a paper that I wrote for the Scientific American magazine in the autumn of 1985, I estimated the true cost as more like $30 billion. I am happy to read that Congressman Nelson's recent estimates of cost now resemble mine. Both are probably still on the low side.

I have no intrinsic opposition to manned flight or to a manned space station if their purposes are described honestly. But I submit that the development of a large space station during the next 10 years is grossly inappropriate to our national predicament in space and to the public mandate for financial responsibility by the federal government.

My overall conclusion is that a space station program, if actually pursued as now projected, will greatly diminish our future advances in space applications of direct human importance and in scientific work of broad appeal to an intelligent citizenry. As a result, our international leadership in space will continue to shrink.

Thank you very much, Mr. Chairman.

Senator PROXMIRE. Thank you very much, Dr. Van Allen for an excellent and impressive statement.

[The statement follows:]

STATEMENT OF JAMES A. VAN ALLEN, UNIVERSITY OF IOWA

A Critique of National Space Policy

Mr. Chairman and members of the committee:

It is no news that the space programs of the United States, both civil and military, have been acutely disabled since the Challenger accident in January 1986. Billions of dollars' worth of high priority commercial, scientific, and military spacecraft are backing up in the launching queue but, within the civil sector, no effective effort is being made to remedy this disgraceful situation. In fact, the present inflexible policy runs in the opposite direction -- that is, to worsen the situation.

The likelihood of such a national disability was foreseen in testimony before this committee on the 29th of June 1971 by Senator Walter Mondale, Thomas Gold, Brian O'Leary, and myself. The committee was then chaired by Senator John Pastore.

At that time, advocates of the development of a fleet of manned space shuttles promised the Congress that each of the proposed shuttles would deliver 50,000 pounds of payload into low earth orbit at a launching cost of $100 per pound; that each shuttle would have a useful lifetime of 100 missions; that by the early 1980's the U.S. would be conducting 50 shuttle flights per year (i.e., about one per week) for civil purposes alone; and that all expendable launch vehicles would thereby be rendered obsolete.

The outrageous optimism of those promises was

described in the above-cited testimony; it is now evident to everyone.

In contrast, the unmanned elements of our space program have consistently delivered on their promises and have usually gone far beyond them.

****

The burden of my testimony today is an assault on prevailing national policy for the conduct of our civil space program -- a policy that ignores the lessons of experience, emphasizes things that do not work, and neglects the things that do work. I make this criticism as one who has devoted over forty years of intensive professional activity to space exploration. There is no one who wishes its continued success more than I do.

I recognize that this committee is concerned with appropriations. But I am not here to suggest that everything can be fixed by another one or two billion dollars per year. On the contrary, I consider that the federal budget for civilian space activities is already at a reasonable level and that the primary fault is one of policy and not one of appropriations.

****

On the 25th of January 1984, I listened very carefully to President Reagan's state-of-the-union address and later got a transcript of it from the Congressional Record. He singled out space exploration as the second of his four great goals for America. That was very pleasant to hear, but I was appalled by his emphasis as represented by the following verbatim excerpt from his address:

"We can follow our dreams to distant stars, living and working in space for peaceful, economic and scientific gain. Tonight, I am directing NASA to develop a permanently manned space station and to do it within a decade.

"A space station will permit quantum leaps in our research in science, communications, and in metals and life-saving medicines which can be manufactured only in space."

He continued with remarks on the enormous potential for commerce in space.

A year later the President reiterated his enthusiasm for space as the "next frontier" and emphasized the bright prospects for manufacturing exotic medicinals for curing disease and extraordinary crystals for revolutionizing electronics -- all in a permanently manned space station.

These statements were so hyperbolic and so ill-founded as to leave an informed person gasping for breath. Indeed they resembled science fiction much more closely than they did sound national policy.

****

In refutation of the President's statements, I submit that the principal elements of our forty years of experience in space are as follows:

First, despite much speculation, only one truly commercial application of space technology has emerged thus far. That is represented by our great global network of communication satellites and the associated industry, including the manufacture of launch vehicles. In addition, private companies have, of course, the central role in selling space equipment and services to

the federal government. But these latter functions do not qualify for the usual understanding of the term commercialization, which means providing products and/or services that pay their own way in the non-governmental market place.

Second, there are many other important utilitarian applications of space technology -- weather observation and forecasting; remote sensing of the earth's surface resources; marine and aircraft navigation; the applied sciences of the sun and of the earth's ionosphere, magnetosphere, atmosphere, and oceans; and military reconnaissance, surveillance, and other applications that are technically similar to those for civil purposes. But all of these applications remain wholly or principally in the area of governmental services.

Third, nearly all of the above mentioned applications of space technology and nearly all of the spectacular advances in the space sciences including planetary exploration and space astronomy have been, are being, and will continue to be accomplished by unmanned, automated, commandable spacecraft. Moreover, most such spacecraft have been and can be launched by expendable launch vehicles and at considerably less cost than by the shuttle -- despite the grossly optimistic predictions to the contrary in the early 1970's -- and with minimal risk to human life.

Fourth, materials processing in space is still an embryonic science. It has significant research interest but, as of the present date, its demonstrated commercial potential is wildly incommensurate with the cost of a space station that has materials processing as one of its principal declared purposes.

A massive two-year study entitled "Space Science in the Twenty-First Century: Imperatives for Two Decades, 1995-2015," under the auspices of the National Academy of Sciences has been completed recently. Apart from biomedical research on human subjects, this study has again found few first-order scientific objectives that require human crews in space, much less a permanently manned space station, during the adopted time frame.

The cost/benefit ratio of secondary purposes such as repair, refurbishment, refueling, and replacement of equipment in earth orbit is, I think, greatly underestimated by advocates of the space station. Indeed, it is much more cost-effective to improve the reliability and versatility of space equipment by preflight developmental and test work and, if necessary, to service it by remotely controlled, unmanned spacecraft. The true "heavy-hitters" in space science and applications have been long-lived satellites and spacecraft based on intrinsically good design, good engineering, and rigorous testing.

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There has been a truly astonishing difference in the responses to the present national emergency in space by the Department of Defense and by the National Aeronautics and Space Administration.

Soon after the Challenger accident, Secretary of the Air Force Edward Aldridge made the forthright public statement: "We made a great mistake in planning exclusive reliance on the shuttle for the delivery of military satellites into space. Believe me, we will not make that mistake again." True to his word, he placed the Vandenburg shuttle-launch facility in caretaker status and immediately initiated the

procurement of a family of expendable launch vehicles for defense purposes. The same position has been taken by the National Oceanic and Atmospheric Administration.

But the administration of NASA has steadfastly refused to recognize the full import of the existing problem and chooses to devote the principal part of its resources to the pursuit of vaguely defined objectives of a futuristic nature. Its 1987 and 1988 budgets emphasize repair of the shuttle system, the procurement of a replacement shuttle, a continuing primary dependence on manned spacecraft for all purposes and the rapid development of a huge space station.

I grant the political face-saving importance, perhaps even the political necessity, of resuming shuttle flights with improved safety. But there is no urgency to building a replacement shuttle and far less urgency to developing a space station. The true national urgency, in my view, is to return to primary dependence on expendable launch vehicles for both civil and military purposes. Yet NASA's 1988 budget, now before this committee, makes provision for the purchase of only one ELV.

Three years ago NASA promised the Congress that it could build a large space station for $8 billion over a ten year period. This estimate, as with the shuttle program estimates in 1971, was so optimistic and so incomplete as to be deceitful -- at least to the uninformed. In a paper that I wrote for the Scientific American magazine in the autumn of 1985, I estimated the true cost as more like $30 billion. I am happy to read that Congressman Nelson's recent estimates of cost now resemble mine. Both are probably still on the low side.

I have no intrinsic opposition to manned flight or to a manned space station if their purposes are described honestly. But I submit that the development of a large space station during the next ten years is grossly inappropriate to our national predicament in space and to the public mandate for financial responsibility by the federal government.

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My overall conclusion is that a space station program, if actually pursued as now projected, will greatly diminish our future advances in space applications of direct human importance and in scientific work of broad appeal to an intelligent citizenry. As a result, our international leadership in space will continue to shrink.

STATEMENT OF L. DENNIS SMITH, PROFESSOR OF BIOLOGY, PURDUE UNIVERSITY

STATEMENT SUMMARIZED

Senator PROXMIRE. Dr. Smith?

Dr. SMITH. Mr. Chairman and members of the subcommittee, thank you for inviting me to appear along with my distinguished colleagues. I, too, have a prepared statement, which I have submitted, which I ask be included in the record.

Senator PROXMIRE. It will be printed in full and we would be glad if you summarize it.

Dr. SMITH. I am chairman of the Committee on Space Biology and Medicine, which is a standing committee of the National Research Council's Space Science Board. The Board is responsible for advising NASA and other elements of our government about science issues in the nation's space program.

Our committee has recently published a report entitled, "A Strategy for Space Biology and Medicine for the 1980's and 1990's." The purpose of this strategy is twofold: to identify and describe those areas of fundamental scientific investigation in space biology and medicine that are both exciting and important to pursue, and to develop the foundation of knowledge and understanding that will make long-term manned space habitation and exploration feasible.

I understand that the report has been made available to the members of the subcommittee and your staff, and my remarks today will be based largely upon the recommendations we made in that report, concentrating on the utility of the space station for biological and medical research.

The committee's report describes in detail our current understanding of the effects of microgravity on humans and other living organisms. Since life as we know it has evolved in the presence of gravity, perhaps it should come as no surprise that plants, animals, and humans show various abnormalities when exposed to the microgravity environment of space.

Knowledge gained principally from the earlier Skylab and shuttle experiments has demonstrated that humans in space experienced considerable physiological problems, including cardiovascular deconditioning, bone demineralization, and muscle atrophy. However, the duration and severity of these effects on long-term missions is not yet clear, nor is it clear to what extent these abnormalities are reversible upon return to a one gravity environment.

More importantly, previous observations have contributed little to our understanding of basic mechanisms, either to clinical questions or to those of basic biological interest. For example, for many plant species microgravity leads to abnormal growth. The development of plants from seed to seed in space has been very difficult to obtain. Similarly, certain phases in the development of animals, including development of organ systems known to be influenced by gravity on Earth, are abnormal in the microgravity environment of space.

Thus, life science research in space has several different but related aspects. It includes both the clinical research necessary to ensure the health and well being of humans as well as emphasizing basic research, exploiting the unique aspects of microgravity to understand the development and function of plant and animal systems.

A permanently occupied space station will, for the first time, permit relatively long-term laboratory experiments to be performed in a microgravity environment using the empirical methods and approaches so successfully employed in hundreds of laboratories on Earth. In this sense, the necessity of a space station for life science research is unique.

To state it differently, it is safe to conclude that without dedicated opportunities on space station, space biology and medicine will not evolve much further as a discipline. That in turn could preclude any long-term human presence in space. With the possible exception of materials science, life sciences in general, and space biology and medicine in particular, is, more than any other space science, in the very earliest stages of discipline development.

There are a number of practical reasons for this: limited flight opportunities, finite numbers of research subjects, and competition with other disciplines for experimental time on the shuttle missions, to name a few. Another major contributor has been the lack of a coherent, well-defined research program.

HEALTH-RELATED ISSUES

Ironically, there appears to be a general perception that the absence of life-threatening medical problems in the manned space program to date implies that there is little need to be concerned about health-related issues on the manned space station or long-term missions. Based on what we know today, this assumption of continued success cannot be rigorously defended.

We have taken no position as to the merits of a manned space program. To do so is not within our purview. However, at this time, we see no reason to conclude that support for the manned program will change. On the contrary, the nation appears committed to continuing a space policy which includes putting humans into space for period of time ranging from days and months to years.

If this nation is committed to a future of humans in space, particularly for long periods of time, it is essential that the vast number of uncertainties about the effects of microgravity on humans and other living organisms be recognized and vigorously addressed.

In addition to the scientific strategy we have outlined in the report, the committee has identified and described three essential facilities necessary to conduct meaningful biological and medical research in space. These are a dedicated life sciences laboratory, a variable force centrifuge, and an animal holding facility.

DEDICATED LIFE SCIENCE LABORATORY

The dedicated life science laboratory is essential for several reasons. One is much of the experimentation requires repetition and manned intervention and is not practical to share with other disciplines. Much of what we have proposed in the report and which needs to be done, especially concerning the physiological changes in space, cannot be done effectively on modules shared with other disciplines.

VARIABLE FORCE CENTRIFUGE

The committee recommended that a variable force centrifuge of the largest possible dimensions be designed, built, and included in the initial operating configuration of the life science laboratory. This is a primary and essential instrument for the future of space biology and medical research. It not only provides for onboard one times gravity controls, but it allows manipulation of gravity at varying levels to determine the effects and the thresholds required to reverse microgravity effects as well as to better delineate the nature of the microgravity effects in the first place.

ANIMAL HOLDING FACILITY

Finally, while humans are subjects of choice in some areas of space research, a large proportion of the research must be conducted on animals, which serve as model systems. In order to conduct that kind of research, a research animal holding facility should be included in the initial operating configuration of the space station's science laboratory.

I was asked to discuss briefly the topic of spinoffs or other benefits that may result from biological or medical research on space station. At this point in time, I don't think I am in a position to predict specifically what those might be.

POSSIBLE SPINOFFS FROM BIOLOGICAL OR MEDICAL RESEARCH

I am aware that, to date, any number of possible spinoffs resulting from the space program in biology and medicine. For the most part, these are summarized in statements by Dr. Arnold Nicogassian, Director of the NASA Life Sciences Program, to the 23rd and 24th session of the United Nations, Subcommittee on Scientific and Technical Affairs, in the Committee on the Peaceful Uses of Outer Space, Earth Benefits from Space, Biomedical Research, in 1986 and 1987.

These spinoffs include development of a variety of techniques and miniaturized instruments to improve health care and diagnosis that already are of enormous benefit to the medical community. While these benefits are valuable to society in and of themselves, the extent to which specific biomedical developments would have evolved in the absence of the space program is unclear.

Thus, I want to reemphasize that there is an even greater fundamental importance to be gained from the program of research we have recommended. A microgravity environment is essential to study basic biological processes known to be influenced by gravitational fields. There is no one single environmental factor that affects organisms so pervasively as gravity.

In order to study the basic mechanism by which gravity influences those processes, it is essential to be able to conduct experiments in the absence of gravity. In some cases, these studies may be related to specific biomedical problems, investigation of bone and muscle loss in space flight, obviously, is related to disuse, atrophy, and osteoporosis, major medical problems. Similar benefits may be expected to result from research on cardiovascular changes. However, again, a major purpose of experiments in space is to learn about basic biological processes.

SUMMARY

In summary, I would like to leave with the following points. There is important research to be done in space biology and medicine as well as in human behavior over the next 10 to 20 years. Plans for a manned interplanetary mission, manned lunar base, or any other conceivable proposal requiring humans to spend years in space demands that we give strong support to a program of research necessary to ensure their well being not only while in space, but upon return to Earth.

The availability of a properly configured space station will provide a never before available opportunity for this field. Without it, we should expect the field to remain primitive and undeveloped. In order to be useful as a biological and medical research facility, it is essential that the space station include the three following elements: a dedicated life sciences module, a variable force centrifuge of the largest possible dimensions, and a well designed animal holding facility.

Thank you.

Senator PROXMIRE. Thank you, Dr. Smith, for also a very impressive statement. I much appreciate it. I think we have a good balance on this panel.

[The statement follows:]

STATEMENT OF L. DENNIS SMITH, CHAIRMAN, COMMITTEE ON SPACE BIOLOGY AND MEDICINE, SPACE SCIENCE BOARD, NATIONAL RESEARCH COUNCIL, NATIONAL ACADEMY OF SCIENCES

It is a pleasure for me to be here before this Subcommittee. Thank you for inviting me to appear along with my distinguished colleagues.

I am Chairman of the Committee on Space Biology and Medicine, a standing committee of the National Research Council's Space Science Board. The Board is responsible for advising NASA and other elements of our government about science issues in the nation's space program. Our Committee has recently published a report, A Strategy for Space Biology and Medicine for the 1980's and 1990's. The purpose of this strategy is two-fold: (1) to identify and describe those areas of fundamental scientific investigation in space biology and medicine that are both exciting and important to pursue and (2) to develop the foundation of knowledge and understanding that will make long-term manned space habitation and/or exploration feasible. In addition to describing the vast number of uncertainties we have about the effects of microgravity on humans and other living organisms, it recommends a scientific research strategy for space biology and medicine for the 1980's and 1990's that we believe is necessary to begin to address these uncertainties. I understand that the report has been made available to the members of the Subcommittee and your staff. My remarks today will be based largely upon the recommendations we make in that report, concentrating on the utility of the space station for biological and medical research.

In September, 1983, the Space Science Board transmitted a letter report to James Beggs, Administrator of NASA titled Space Science in a Space Station Era.(see Attachment A) The overall finding of the

report was "... the Space Science Board has addressed the issue of the space science need for a space station. It found no need for a space station to support missions addressing high priority science issues for the next two decades. On the other hand, it found that a suitable (emphasis added) space station could offer important services to space science in the more distant future." The report goes on to include an important qualification concerning space biology and medicine, that deserves repetition here. "A commitment by the nation to long-duration human space flight, whether in Earth orbit or beyond, calls for the establishment of a facility for space biological and medical research on the effects of individuals of a very long exposure to the 'low g' environment. In this sense, the relationship of the life sciences to a space station is a special one." The Committee on Space Biology and Medicine strongly endorses this position.

It is not an understatement for me to say that the strategy for space biology and medical research that we have recommended presumes the availability of a space station. While there are any number of experiments that can and should be conducted on the ground, their results only become meaningful when compared with those obtained in space.

The relatively short missions that characterize the Space Transportation System do not easily lend themselves to the requirements of space biology and medical research. While my committee has strongly endorsed enhancing NASA's ground-based program of research in space biology and medicine (particularly during the period of time before the shuttle flies again) we have been equally strong in our recommendations concerning the need for dedicated

periods of time of increasing duration on space station once it becomes available.

With the possible exception of materials science, life sciences in general, and space biology and medicine in particular is, more than any other space science, in the very earliest stage of discipline development. There are any number of practical reasons for this -- limited flight opportunities, finite numbers of research "subjects," and competition with other disciplines for experimental time on Shuttle missions, to name a few. Another major contributor has been the lack of a coherent, well-defined reseach program. Ironically, there appears to be a general perception that the absence of life-threatening medical problems in the manned space program implies that there is little need to be concerned about health-related issues on a manned space station. Based on what we know today, this assumption of continued success cannot be rigorously defended.

We have taken no position as to the merits of a manned space program. To do so is not within our purview. However, at this point in time, we have no reason to conclude that support for the manned program will change. On the contrary, the nation appears committed to continuing a space policy which includes putting humans into space for periods of time ranging from days to months to years. To quote from the Foreword of our strategy report, "If this nation is committed to a future of humans in space, particularly for long periods of time, it is essential that the vast number of uncertainties about the effects of microgravity on humans and other living organisms be recognized and vigorously addressed. Not to do so would be imprudent at best; quite possibly, irresponsible."

As I have already indicated, my committee's report describes in

detail our current understanding of the effects of microgravity on humans and other living organisms. Life as we know it has evolved in the presence of gravity. It comes as no surprise that plants, animals, and humans show various abnormalities when exposed to the microgravity environment of space. Knowledge gained principally from the earlier Skylab and shuttle experiments have demonstrated that humans in space experience considerable physiological problems including cardiovascular deconditioning, bone demineralization, and muscle atrophy. However, the duration and severity of these effects on long-term missions is not yet clear, nor is it clear to what extent these abnormalities are reversible upon return to a 1-g environment. More importantly, previous observations have contributed little to our understanding of basic mechanisms, either to clinical questions or to those of basic biological interest. For example, for many plant species, microgravity leads to abnormal growth. The development of plants from seed to seed has been very difficult to obtain. Similarly, certain phases in the development of animals, including development of organ systems known to be influenced by gravity on earth, are abnormal in the microgravity environment of space. Thus, life sciences, research in space has several different, but related aspects. It includes both the clinical research necessary to ensure the health and well being of humans, as well as emphasizing basic research -- exploiting the unique aspects of microgravity to understand the development and function of plant and animal systems.

Unlike the more traditional space sciences that rely principally on remote observation, space biology and medicine require interactive experimental approaches in which hypotheses, experimental data, and initial conclusions follow in iterative sequence. Establishment of

new ideas frequently requires intervention in experimental design during the course of experiments, often resulting in modification of hypotheses and generation of new ideas. A permanently occupied space station will, for the first time, permit relatively long-term laboratory experiments to be performed in a microgravity environment using the empirical methods and appraoches so successfully employed in hundreds of laboratories on earth. In this sense, the necessity of a space station for life sciences research is unique.

Results obtained from ground-based research, coupled with those from the limited number of flight opportunities, has allowed the generation of models. These models can only be verified by sustained experimental opportunities in space, a condition that is also required to create and verify new models. It is safe to state that without dedicated opportunities on space station, space biology and medicine will not evolve much further as a discipline. That in turn could preclude any long-term presence in space.

In addition to the space station itself, we have identified and described three essential facilities necessary to meaningful biological and medical research in space. They are: (1) a dedicated life sciences laboratory (2) a variable force centrifuge and (3) an animal holding facility.

DEDICATED LIFE SCIENCES LABORATORY

One of the major reasons for the slow progress in space biology and medicine over the last decade has been the lack of flight opportunities. There were no U.S. initiatives in human biology in the time between the Skylab missions and the start of the space shuttle flights. In the same period, there were only a handful of non-human biological experiments. To date, large numbers of life

sciences payloads have been carried on only two shuttle missions, Spacelabs 1 and 3, both of which were designed as verification tests. If significant progress is to be made by the end of the century, then the space biology and medicine scientists will need continuous access to spaceflight opportunities. Most of these experiments require manned intervention. Based on the dual requirements of continuous access and manned intervention, the committee recommends that there be a dedicated life sciences laboratory on the space station.

Scientists must work closely with designers and engineers at every stage in the development of the life sciences laboratory and of the equipment that is to be used within. The laboratory must be flexible enough to be rapidly converted to accommodate the needs of different types and combinations of experiments. As this dedicated laboratory will serve many different functions, provision must be made for inserting, removing, or reconfiguring equipment, racks, and dividing walls.

VARIABLE FORCE CENTRIFUGE

In its report, the Committee on Space Biology and Medicine makes the following recommendation:

"We have been apprised of the engineering problems involved in the inclusion of a large centrifuge in a freely floating space station. The committee still recommends that a Variable Force Centrifuge (VFC) of the largest possible dimensions be designed, built, and included in the initial operating configuration of the Life Sciences Laboratory. It does so because a VFC is an essential instrument for the future of space biology and medicine."

The VFC not only provides an onboard 1-g control for experiments

concerned with the effects of microgravity on biological processes, it also provides the opportunity to study the effects of varying gravitational forces on such processes. Concerning the deleterious effects of microgravity that have already been documented, a VFC will allow investigators to also determine whether there is a threshold force required for a response to occur or, conversely, to reverse a given response. The centrifuge should be large enough to accommodate experiments on primates, possibly humans, rodents, and larger plants. A VFC is an essential instrument for the future of space biology and medicine.

The Space Science Board has documented the need for a centrifuge for space biology and medical research in at least seven reports, going back from nearly twenty years ago to the present. Furthermore, virtually every other group that advises NASA on life sciences has also made this recommendation. They range from the President's National Commission on Space to the NASA Life Sciences Advisory Committee and the Task Force on Scientific Uses of the Space Station a group chaired by Peter Banks.

Animal research will be required in several areas, including sensorimotor adaptation, muscle atrophy, bone and mineral metabolism and developmental biology. A research animals holding facility should be included in the initial operating configuration of the space station's life sciences laboratory. It should modular and flexible and should accommodate both large and small animals. Advances in biology have often been based on the same use of comparative methods. Space biology would benefit similarly from the availability of a wide range of animals. The individual units of the facility should be easily mated to the variable force centrifuge and other equipment.

APPLICATIONS AND BENEFITS DERIVED FROM SPACE BIOLOGY AND MEDICINE

You asked me to discuss the topic of "spinoffs" or other benefits that may result from biological or medical research on space station. At this point in time I am not in a position to predict specifically what those might be. I am, however, aware that to date, there have been any number of "spinoffs" resulting from the space program in biology and medicine. For the most part, these are summarized in statements by Dr. Arnold E. Nicogassian, M.D., Director of the NASA life sciences program, to the twenty-third and twenty-fourth sessions of the United Nations Subcommittee on Scientific and Technical Affairs, in the Committee on the Peaceful Uses of Outer Space, Earth Benefits from Space Biomedical Research, 1986 and 1987. These "spinoffs" include development of a variety of techniques and miniaturized instruments to improve health care and diagnosis that are of enormous benefit to medicine.

While these benefits are valuable to society in and of themselves, the extent to which specific biomedical developments would have evolved in the absence of the space program is unclear. I want to reemphasize that there is an even greater fundamental importance to be gained from the program of research we have recommended. A microgravity environment is essential to study basic biological processes known to be influenced by gravitational fields in both plants and animals. In some cases these studies may be related to specific biomedical problems; investigation of bone and muscle loss in space flight obviously is related to disuse atrophy and osteoporosis, major medical problems. However, the major purpose of experiments in space is to learn about basic biological

processes. The response mechanism of living systems to gravitational input cannot be studied on earth because it is impossible to remove the continuing gravitational input for sustained periods of time. The space station alone offers this opportunity.

SUMMARY

In summary I would like to leave you with the following points:

- There is important research to be done in space biology, medicine behavior over the next 10 - 20 years.
- Plans for a manned interplanetary mission, manned lunar base or any other conceivable proposal requiring humans to spend years in space demands that we give strong support to a program of research necessary to ensure their well-being not only while in space, but upon return to earth.
- The availability of a properly configured space station will provide a never before available opportunity for this field. Without it, we should expect the field to remain primitive and undeveloped.
- In order to be useful as a biological/medical research facility, it is essential that the space station include the three following elements: (1) A dedicated life sciences module, (2) a variable force centrifuge of the largest possible dimensions and (3) A well designed animal holding facility.

I would be happy to answer any questions you might have now or to provide written responses for the record. Thank you.

SPACE SCIENCE IN A SPACE STATION ERA

In a recent statement entitled, "Space Science Board Assessment of the Scientific Value of a Space Station," the Space Science Board has addressed the issue of the space science need for a space station. It found no need for a space station to support missions addressing high priority science issues for the next two decades. On the other hand, it found that a suitable space station could offer important services to space science in the more distant future.

The Space Science Board realizes that the nation may decide to commit itself to the deployment of a space station in support of needs and objectives other than or in addition to those of space science alone. The characteristics of such a space station should be carefully determined to conform to the principal activity that it is intended to support. For example, it is not obvious that a space station optimized as a transportation node for travel between the Earth and other solar system objects would also be an entirely suitable platform from which to launch and support science and applications missions. Whatever the eventual properties of such a space station, there will probably be a set of high priority science missions that require orbits and operational support for maximum effectiveness other than those available from that station. If a space station program should be undertaken and it is meant to be useful to space science, the Space Science Board urges that the means to initiate and operate space science missions in a timely fashion and in reasonable accord with priority ordering of those missions be maintained. Ordering of missions would then be determined by scientific priority rather than the nature of the launch or support system required. The Board also urges that the scientific program be structured so as to be protected from delay in space station development or changes in its capability.

The Board also wishes to make the following specific recommendations and observations.

Scientific instruments that can be deployed in orbits compatible with space station orbits should be flown in optimal scientific orbits and on separate platforms if that is necessary to preserve them from contamination, interference, and degradation of pointing stability and control that may be associated with the manned modules.

If the space station is designed to provide a servicing capability beyond that provided by the shuttle, that capability should allow retrieval of instruments from a wide variety of orbits.

The deployment of a space station designed in part to support space science implies an increase in the level of space science activity above that presently planned. If such a space station is to be utilized effectively, the space station system should be accessible and affordable for scientific use, and there should be a real increase in the level of support for that activity.

A commitment by the nation to long duration human space flight, whether in Earth orbit or beyond, calls for the establishment of a facility for space biological and medical research on the effects on individuals of very long exposure to the "low g" environment. In this sense, the relationship of the life sciences to a space station is a special one.

Thus, a manned space station could eventually provide significant opportunities for a number of disciplines in space science provided there is a commensurate increase in the total level of space science activity. Realization of those opportunities would depend on the extent to which the capability to carry out space science research is kept viable, important experimental and theoretical activity is continued, and new endeavors are initiated while the space station is being developed. After the space station becomes operational, realization of those opportunities would depend on the provision of a sufficient number and variety of flight opportunities, many involving unmanned space craft and flight to regions of space near the Earth and further out in the solar system at distances and locations inaccessible to a manned platform.

STATEMENT OF RICCARDO GIACCONI, DIRECTOR, SPACE TELESCOPE SCIENCE INSTITUTE

Senator PROXMIRE. Dr. Giacconi?

Dr. GIACCONI. Mr. Chairman, members of the subcommittee, I have submitted a statement in writing, which I would like to be placed in the record.

Senator PROXMIRE. It will be printed in full in the record, sir.

SPACE STATION MISSION CRITICAL

Dr. GIACCONI. Thank you. I would like to say at the onset that I support the space station if designed specifically to carry out the program of manned exploration of the solar system, but I am concerned about the confusion which is produced by the attempt to support this space station on the basis of science and high technology to the detriment of both space science and manned exploration.

High technology development, in my opinion, is better supported by a balanced independent science program than by artificial injection of high technology in the space station program. NASA's mandate as specified by the National Aeronautics and Space Act of 1958 includes the conduct of space activities which contribute materially to the expansion of human knowledge of phenomena in the atmosphere and space and to the preservation of the role of the United States as a leader in aeronautics and space science and technology.

A vigorous space science program is a necessary component of any effort to carry out this mandate. In fact, since the onset of NASA's operation, a significant fraction of NASA's budget—10 to 15 percent in the 1960's and 20 to 25 percent in the 1970's and 1980's—has been expended to carry out activities in the area of space science and applications. This represents a substantial financial commitment for the agency to carry out its mandate to foster scientific research.

Although, in the late 1970's and early 1980's, the traditional application areas—Earth observations, life sciences, materials and communications research—were greatly increased at the expense of the traditional space sciences—astronomy, solar terrestrial physics, and planetary exploration.

The traditional space sciences flourished in the 1960's and 1970's and gave us an unprecedented series of spectacular scientific discoveries.

The exploration missions to the planets, the study of the Sun and its environment, and the new astronomical vistas opened in the entire range of the electromagnetic spectrum are internationally recognized achievements.

Almost all of the missions which produced these results were based on the use of automated spacecraft launched by expendable launch vehicles. This flow of exciting missions and results was significantly decreased in the last few years—even prior to the loss of *Challenger*—and has now nearly come to a complete halt.

The report of the NASA Advisory Council, entitled, "The Crisis in Space and Earth Science," of November 1986, clearly documents these points. The question that confronts us, however, as scientists is how to recover from this disastrous situation and how to provide the conditions in which the enormous potential of U.S. space science can be fruitfully engaged at an internationally competitive level.

I believe that to give a proper remedy, it is also necessary to have a proper diagnosis. Certainly the nearly exclusive reliance on the space shuttle transportation systems in the 1980's has led to the current grounding of all space activities due to a single point failure and must be changed.

USE OF ELV'S ADVOCATED

Several groups in the nation, including NASA's own advisory committees, advocate the use of expendable launch vehicles as a necessary adjunct to STS capabilities. The NASA Advisory Committee task force on issues of a mixed fleet went further by stressing that ELV's should always be used, except when man's participation is absolutely required.

One result of past exclusive reliance on the space shuttle transportation system has been an improper intertwining, in my opinion, of two basic activities of NASA: the conduct of space science and of manned exploration. It has contributed to the current conditions because the objectives and requirements of the manned exploration program have superseded the objectives and requirements of the science program.

This has affected both the execution of the science program and the setting of scientific priorities. Given a scientific objective to be pursued, it should be possible for scientists to consider alternate modes of execution, either using the space shuttle transportation system or expendable launch vehicles, and to choose the most appropriate spacecraft, orbits, communications and data systems to carry out the science in the most effective and efficient manner.

Instead, the prior decision to use shuttle transportation system forced one alternative to be pursued regardless of expense, risk, or scientific ineffectiveness. In effect, priority and funding started to flow toward the science that could utilize the unique capabilities of shuttle transportation systems, rather than to the best science.

NO SCIENTIFIC NEED FOR SPACE STATION

This situation could recur in the discussion of space station capabilities for conducting science, which we are having today. The Space Science Board of the National Academy of Sciences stated on September 9, 1983, that the Board "sees no scientific need for this space station for the next 20 years."

I concurred in that statement as a member of the Space Science Board, and believe that it is as true today as it was then: we have a well thought out program of important and exciting science yet to be done, but it is not getting done due to a lack of flight opportunities and funds.

It makes little sense to worry about what more ambitious mission we may do in the year 2015, by use of space station capabilities, when we may, by then, barely have been able to carry out our current programs already on the planning boards for the 1980's and early 1990's.

I feel that the remedy to this state of affairs is to recognize that science and manned flight programs each have worthwhile goals and objectives, but to refrain from making one subservient to the other. Let us agree that a program of manned space exploration is an important national objective. Let us set distant goals as envisioned by the National Commission on Space in 1986. Let us then design our space transportation system space station and any other near term future objective as stepping stones to those distant goals.

But let us not muddy the waters by claiming that the space station and space science are necessary to each other. Simultaneously, let us commit to carry out a vigorous program of space science with goals and objectives set by scientific criteria of excellence and opportunity, rather than by the need to support this or that transportation system or logistics mode.

Expansion of man's knowledge of the universe is a noble goal in itself. We can be absolutely sure that a robust program of space science will yield important and even fundamental discoveries, which will receive worldwide recognition. As in the past, such programs can be expected to result in major technological innovations.

SEPARATION OF SCIENCE AND TRANSPORTATION SYSTEMS

In order to achieve this end, I am convinced that the space science program of NASA must be given the means to be independent of the manned program transportation system except when it chooses to be a customer. The Office of Space Science and Application's budget should contain the necessary financial resources to carry out the science program in its entirety by use of expendable launch vehicles.

Support for the fraction of scientific investigations that absolutely need manned assistance should be paid for through this budget. Such programs should, however, compete for resources on the basis of scientific worth with other scientific programs.

I am convinced that by use of such an approach, and I would like to stress this point, we could carry out a vigorous program of space sci-

ences with resources no greater than are currently expended. I have described some of these issues in more detail in some papers which I have recently submitted for publication.

SPACE STATION VITAL STEP IN MANNED EXPLORATION OF SOLAR SYSTEM

In conclusion, I would like to see a space station designed and implemented for the goal for which I believe it is appropriate; namely, as a vital step in manned exploration of the solar system. I would also like to see an independent and vigorous space science program which is free to rely on the use of automated spacecraft and the use of expendable launch vehicles.

Senator PROXMIRE. Thank you, Dr. Giacconi for a vigorous, forthright statement.

[The statement follows:]

Statement of Riccardo Giacconi, Director, Space Telescope Science Institute

NASA's mandate, as specified by the National Aeronautics and Space Act of 1958, includes the conduct of space activities which contribute materially to the expansion of human knowledge of phenomena in the atmosphere and space and "to the preservation of the role of the United States as a leader in aeronautics and space science and technology." A vigorous space science program is a necessary component of any effort to carry out this mandate.

In fact, since the onset of NASA's operation, a significant fraction of NASA's budget (10 to 15% in the 1960's and 20 to 25% in the 1970's and 1980's) has been expended to carry out activities in the area of space science and applications. This represents a substantial financial commitment for the agency to carry out its mandate to foster scientific research, although in the late 70's and early 80's, the traditional application areas (earth observations, life sciences, materials and communication research) were greatly increased at the expense of the traditional space sciences (astronomy, solar terrestrial physics and planetary exploration).

The "traditional" space sciences flourished in the 60's and 70's and gave us an unprecedented series of spectacular scientific discoveries. The exploratory missions to the planets, the study of the sun and its environment, and the new astronomical vistas opened in the entire range of the electromagnetic spectrum are internationally recognized advancements.

Almost all of the missions which produced these results were based on the use of automated spacecraft launched by expendable launch vehicles. This flow of exciting missions and results was significantly decreased in the last few years -- even prior to the loss of Challenger -- and has now nearly come to a complete halt.

The report of the NASA Advisory Council (NAC) entitled "The Crisis in Space and Earth Science" of November 1986, clearly documents these points. The questions that confront us as scientists are how to recover from this disastrous situation and how to provide the conditions in which the enormous potential of U.S. space science can be fruitfully engaged at an internationally competitive level. To give a proper remedy, it is necessary to have a proper diagnosis.

Certainly the nearly exclusive reliance on the Space Shuttle Transportation System (STS) in the 1980's, has led to the current grounding of all space activities, due to a single point failure and must be changed. Several groups in the nation, including NASA's advisory committees, advocate the use of Expendable Launch Vehicles (ELVs) as a necessary adjunct to the STS capabilities. The NAC task force on issues of a mixed fleet went further by stating that ELVs should always be used except when man's participation is absolutely required.

One result of the past exclusive reliance on the STS has been the improper intertwining of two basic activities of NASA, the conduct of space science and the conduct of a manned exploration program. It has contributed to the current conditions because the objectives and requirements of the manned exploration program have superceded the objectives and requirements of the science program.

This has affected both the execution of the science program and the setting of scientific priorities. Given a scientific objective to be pursued, it should be possible for scientists to consider alternative modes of execution, either using the STS or ELV, and to choose the most appropriate spacecraft, orbits, communications and data systems to carry out the science in the most cost effective and efficient manner. Instead the prior decision to use STS forced one alternative to be pursued regardless of expense, risk and scientific ineffectiveness.

In effect, priority and funding started to flow toward the science that could utilize the unique capabilities of STS, rather than to the best science. This situation could recur in the discussion of space station capabilities for conducting science.

The Space Science Board of the NAS stated on September 9, 1983, that the Board "...sees no scientific need for this space station for the next twenty years". I concurred in that statement as a member of SSB, and believe that it is as true today as it was then. We have a well thought out program of important and exciting science yet to be done, but it is not getting done due to a lack of flight opportunities and funds. It makes little sense to worry about what more ambitious missions we may do in the year 2015, by use of Space Station capabilities, when we may, by then, barely have been able to carry out our current programs already on the planning boards for the 1980's and early 1990's.

I feel that the remedy to this state of affairs is to recognize that science and manned flight programs each have worthwhile goals and objectives, but to refrain from making one subservient to the other.

Let us agree that a program of manned space exploration is an important national objective. Let us set distant goals as envisioned by the National Commission on Space in 1986. Let us then design our STS, Space Station and any other near term future objective as stepping stones to those distant goals. But let us not muddy the waters by claiming that the Space Station and Space Science are necessary to each other.

Simultaneously let us commit to carry out a vigorous program of space science with goals and objectives set by scientific criteria of excellence and opportunity, rather than by the need to support this or that transportation system or logistic mode. Expansion of man's knowledge of the universe is a noble goal in itself. We can be absolutely sure that a robust program of space science will yield important and even fundamental discoveries, which will receive worldwide recognition. As in the past, such programs can be expected to result in major technological innovations.

In order to achieve this end, I am convinced that the space science program of NASA must be given the means to be independent of the manned program transportation system except when it choses to be a customer. The OSSA budget should contain the necessary financial resources to carry out the science program in its entirety by use of ELVs. Support for the fraction of scientific investigations that absolutely need manned assistance should be paid for by the OSSA budget. Such programs should, however, compete for resources on the basis of scientific worth with other scientific programs. I am convinced that by use of such an approach, we could carry out a vigorous program of space sciences with resources no greater than are currently expended. I have described

some of these issues in more detail in a paper presented at the American Association for the Advancement of Science and in an article submitted for publication.

In conclusion, I would like to see a Space Station designed and implemented for the goal for which I believe it is appropriate, namely as a vital step in manned exploration of the Solar System. I would also like to see an independent and vigorous space science program which is free to rely on the use of automated spacecraft and the use of Expendable Launch Vehicles.

INFLUENCE OF THE MEDIA ON SPACE PROGRAM

Senator PROXMIRE. Dr. Sagan, my first question has to do with the influence of the media, particularly television, on our space program. At times I wonder if NASA hasn't become a captive of the media. After all, the best way for NASA to get on the evening news is with a big space spectacular, whether it is a manned mission to the Moon, a complex shuttle trip involving the repair of a satellite in low Earth orbit, or the construction of an elaborate space station. On the other hand, unmanned flight producing significant scientific results may have less media appeal.

I would like to get your thoughts, because you obviously have used television wonderfully well, I mean that in the best sense, to promote science in general, and the wonders of space in particular.

Do you think the media may be responsible in part for our emphasis on projects such as the space station?

Dr. SAGAN. Senator Proxmire, I see the media amplifying both the accomplishments of manned space flight and unmanned space flight. It is true that there is a colossal failure of the imagination in the media, so that they readily know how to talk about putting human beings up in a tin can in Earth's orbit, and then bringing them down again. Whereas something involving science involves somewhat greater effort on their part.

But if you look, for example, at the Voyager spacecraft, when it encountered the Saturn system in 1981, the planet Saturn made the covers of Time, Newsweek, and U.S. News and World Report. I think, in general, NASA could do a much more effective job in communicating the results and excitement and future prospects.

Senator PROXMIRE. What I had in mind is that there is nothing like that human interest identification we have when you see a Jake Garn out there in space, or any other astronaut. You associate with him that it takes a lot of courage, and it is at enormous risk.

Dr. SAGAN. No question.

Senator PROXMIRE. This has a great appeal for all of us watching it.

Dr. SAGAN. Just as in bull fights and hockey, there is some additional interest due to the question of individual jeopardy. But what you express, Senator Proxmire, is the prevailing wisdom that people can only identify with people and not with robots.

My own view is that that is undemonstrated. If you want to take Star Wars—I mean the original Star Wars, not the more recent corruption—

R2D2 and C3PO got quite a lot of resonance, a lot of emotional interest was directed at them.

The state of robotics and artificial intelligence is such that very competent machines capable of branched contingency-free decisionmaking can be, in fact, are—Voyager in some sense is such a spacecraft—being sent into space.

I don't think this is an insuperable problem, but it takes a little more effort than identification with human beings in Earth orbit, but after all, if the idea is just to put human beings in jeopardy so that people can identify with them, there are a lot less expensive ways to do that.

Senator PROXMIRE. Thank you, Dr. Sagan.

Dr. Van Allen, your opening remarks reminded me of Oscar Wilde's observation that, "Experience is a name we give our past mistakes, and policy is the name we give our future mistakes." [Laughter.]

VALUE OF SPACE MATERIALS PROCESSING

In our previous hearing, Dr. Fletcher was asked by Senator Grassley about NASA's emphasis on manned flight when nearly all of the important scientific results in space have resulted from the use of unmanned satellites and spacecraft.

This latter statement was drawn from an article quoting you, Dr. Van Allen, and Mr. Fletcher answered, "There are many other missions, however, besides physics and radiation balance that can only be done with a space shuttle. The best example is materials processing. You can do man-tended missions, space processing we call it, materials processing, in no other way except on a shuttle or on a space station. Space labs were specifically designed to do that."

I would like you, Dr. Van Allen, to comment on the real value of space materials processing, and whether a permanently manned space station is necessary to do this type of work?

Dr. VAN ALLEN. Yes, sir. Thank you, Mr. Chairman. I think that is one of the most falsely overstated purposes of space flight at the present time, materials processing.

A few years ago, there was a zip term called manufacturing in space, the general representation of which was that within a few years, especially with the help of the space station, there would be enormous quantities of unique pharmaceuticals, unique crystalline materials being produced in space. There would be regular shuttle flights up to the station to deliver raw materials, shuttle flights returning the finished products to Earth, and would become a major commercial industry.

That is such a hyperbolic assessment of the prospects that I consider it false and deceitful, because it works off an extremely minute base of experience and judgment at the present time. The research interest in processing materials in space is a very legitimate one, and has been pursued in a very meager way up to the present time.

The promise of enormous manufacturing facilities in space has no reliable foundation in human experience up to the present time. Nonetheless, it remains a good research field. I don't disagree with that in any sense.

COOPERATION WITH U.S.S.R. IN SPACE AND MEDICINE PROGRAMS

Senator PROXMIRE. Dr. Smith, much of your statement dealt with the importance of observing the effects of weightlessness on man. Isn't that a good argument for involving the Soviet Union in our space and medicine programs?

After all, they have much more experience with extended space flight than we have. It would reduce the cost greatly and this is primarily medical rather than military in purpose. Why can't we work with them closely?

Dr. SMITH. I don't see any obvious reason why we couldn't. They are obviously, way ahead of us in this area. They have been doing life science experiments in space on almost every flight, both short term and long term, certainly since the mid-1970's.

I understand, and I am not an expert in this field, but we have recently signed or are signing a treaty with the Russians which will allow us access to information they have been obtaining from space flights. We have not been privvy to that information on an actual basis, as I understand it.

So, I certainly wouldn't object to that kind of interaction. I think it is both fundamentally important and necessary.

SPACE STATION AS LOW-TECHNOLOGY ENTERPRISE

Senator PROXMIRE. Dr. Giacconi, Dr. Fletcher was before this committee a few weeks ago, as I said before, and in his prepared statement he said, "The space station is essential to regaining a position of leadership in space for the United States. Its practical benefits will be many. It will be an orbiting laboratory for the conduct of science, the development of new technologies, and the stimulation of commercial enterprises."

I would like to get your reaction, Dr. Giacconi, of that statement in view of support for the Space Science Board's statement that, "It sees no scientific need for the space station for the next 20 years."

Dr. GIACCONI. I think that the points I have already made in my testimony are directed to a basic belief that a space station is a low technology enterprise. This is precisely why the Soviet Union has been ahead of us, because it doesn't require very sophisticated technology.

To think that a space station will promote technology, or to try to artificially inject it into it, I think it is a mistake. As I mentioned earlier, we think a balanced program of independent space research would do much more.

By the way, I think that the fact that it isn't a high-technology operation is intrinsic. You have to be extremely conservative when you deal with man, and if high propulsion systems have not really fundamentally changed and you want to have very safe, very conservative systems.

Now, as to the issue about space science, I think there is no question that if you want to have long duration flights, and if you want to have people live and go on in zero gravity, if that is your objective, then, of course, you have to find out on what basis that can happen.

I presume there is some validity to the programs which are proposed. I am not terribly convinced that this is fundamental biology, in the sense that gene mapping might be.

As to material sciences, I think Dr. Van Allen has already made some statements with respect to that side. With respect to all the other sciences, we would do much better if we were allowed to use, or not to use, manned facilities as we require. Basically, most of the programs that we have on the table now do not require man attendance.

LEADERSHIP VALUES

Senator PROXMIRE. Dr. Smith, Mr. Fletcher went on to say in that very statement that I quoted earlier, he said that, "Leadership values of the space station may exceed its considerable practicality."

Leadership is a pretty intangible concept. How do you view the space station as a mechanism for asserting leadership values? What does that mean?

Dr. SMITH. I think in several areas—for example, in my own discipline which involves biological sciences—this nation has been a devout leader in almost every major field for years and years. My colleague mentioned gene mapping. Those kinds of technologies essentially evolved in the United States and we have been a forerunner in those approaches.

In the same kind of science that we have been talking about, which I would define by the way as fundamental science of the same magnitude as gene mapping, we are not leaders right now, and I think in order to resurrect that position, we need to establish a rigorous, well-funded, and well-balanced program of space research.

We simply have not had the opportunities to do that in the past, and until we get opportunities to undertake that kind of endeavor we lose a leadership role, whether it is perceived by persons in this country, or more importantly by the international community.

Senator PROXMIRE. Dr. Sagan, would you comment on that.

Dr. SAGAN. Yes; leadership is vague, but if we are concerned with leadership, it seems to me, we have to decide what the goal of NASA is, and until the United States' executive and legislative branches together figure out what NASA's long-term goal is, it is going to be very hard to talk about leadership.

The Soviet Union is at least a decade ahead of the United States in long duration Earth orbital space flight and space station, and so on. Is the most effective, most appropriate way for the United States to regain "leadership in space" in that area, or might there be much more effective, much better cost/benefit ratios in some other areas?

I find the statement that you quoted from the Administrator exceedingly vague and hard to understand.

Senator PROXMIRE. Thank you, sir.

Senator Garn?

COOPERATING WITH THE SOVIETS

Senator GARN. Thank you, Mr. Chairman. I might make one comment on the difficulties of cooperating with the Soviets, particularly in the medical area.

I have attended several conferences, as the first full-time human guinea pig in space, to be able to talk about my experiences. I met in an international conference with several Soviet Cosmonauts and doctors specializing in space medicine. I gave my usual candid account of what had taken place to me on *Discovery*, and asked this one Soviet doctor, with these other Soviets at the table, if he would tell me something about their experiences, and he said, "You don't understand, Senator, because of the superiority of the Soviet system, our cosmonauts do not get ill."

And he said it with a straight face. I don't know how you deal with that kind of hidden agendas, because they throw up just like Americans do. There is no doubt about it. I am going to use my time not as much for questions as to make a few comments about the testimony.

GENERAL COMMENTS OF SENATOR GARN

For 6 or 8 years, I have been rather deeply involved in space as a layman. I don't want to be offensive because with these distinguished gentlemen, I certainly would not in any way try and debate science with them. I am not trained. I am not qualified to do that, but I would suggest that in one area I have some expertise they do not. I think I know a little bit more about manned space flight than anyone else in this room.

It is not easy to describe that experience but, nevertheless, I have done it. As I look at the testimony today, it illustrates the difficulty of having a rational coherent national policy. Because I have read the statements of every one of these gentlemen over the years, and virtually every other noted scientist in the space field, to try and educate myself, and to learn as a layman.

What happens is that I don't care what kind of a space station you design. It makes no difference whatsoever. We can find a noted scientist who will come in and say it is a lousy piece of junk and shouldn't have been designed in that way.

That is the difficulty of coming up with a policy when you have people that are famous in their field; nobody can question their credibility, but have vast differences of opinion. Even on this panel, today, here is Dr. Sagan, who I agree with. I think we ought to go to Mars. I think it is a shame we have not made that decision, and we are not sending people to Mars.

Then, Dr. Van Allen is virtually the opposite, finds very little use for men and women in space, whatsoever. Dr. Giacconi somewhat different. Dr. Smith, here, finds great uses for medical science and technology. We can bring four more in tomorrow, eight more in the next day, and we will find the same diversity.

Then, when you put all of this in to the political realm of trying to find dollars in the difficult budget situation, and an OMB that doesn't understand any of this, then, you see the difficulties. I don't know, Mr. Chairman, I don't know how we ever come up with a rational space policy.

I loved the report of the commission last year on where we ought to be going, the goals and the visions of what we ought to be doing, but that isn't going to happen. But, we find extremes on every side.

MANNED VERSUS UNMANNED VEHICLES

I find it very difficult to view the Nina, the Pinta, and the Santa Maria without Columbus on board. I saw a cartoon shortly after the *Challenger* accident that showed the Conastoga wagon with nobody on the buck board and nobody in the back and the caption said, "Too dangerous out in the West, so we are going to only send unmanned vehicles."

There is absolutely no doubt, Dr. Van Allen, that you are correct. It is indisputable that it is cheaper to put ELV's into space. There is no doubt about that. At this point more sciences come from unmanned vehicles. But you take an extreme position and there are people on the other side of the coin who want nothing to do but send up men with leather helmets and silk scarves—the old test pilot—and put them in space and say, "Gee whiz, we sent men into space and we brought them back."

What I have been trying to achieve over the years is some balance between those two extremes, because I see great value in both. The only coherent policy that I see that makes sense is a role for both, because no matter how good the unmanned vehicle is, there is something that cannot be judged in terms of dollars and cents: the value of men and women and their experiences in space.

That has always been true throughout our history. The value of that human spirit that you or I or no one else can quantify or put a dollar value on. Let me give you one example: I am sure that you would be totally opposed to Christa McAuliffe flying in space. It is of no value whatsoever, ridiculous to send a school teacher into space, and you probably think I shouldn't have gone and that is fine. A lot of other people thought so too, but I really don't care. I enjoyed every minute of it.

A role that I did not anticipate in flying, beyond medical experiments, and being a gopher, and sewing a fly swatter together to try and catch a switch on a satellite and make it work, was the fact that I did not anticipate being in dozens and dozens of schools all over this country.

There isn't a week that goes by that I don't have requests to do that, and I am not a trained educator, any more than I am a trained scientist. It is a role that I enjoy doing more than anything else I do, talking to young people and getting them excited about science education, as someone who got a degree in banking and finance, because of the future that I see for all mankind in scientific technology and what it will do for social problems on this country.

With the dropout problem and the problems that we have in education and having truly educated people, to be able to get people excited about that might lower the dropout rate. If I can have that kind of an impact, that is a total intangible that I can place no value on whatsoever in terms of dollars and cents.

Then a fantastically wonderful teacher like Christa McAuliffe, what kind of an impact, if she had had the opportunity to see what I did, to experience manned space flight, with no benefit whatsoever scientifically, doing no scientific experiments, nothing coming back, to be able to communicate that and the impact I believe she could have had on the school system of this country, and future scientists to take the place of the Dr. Van Allens, Sagans, Smiths, and Giacconis.

That is an intangible that I cannot place a value on of men and women being in space, so what I am pleading for is balance. Let's not go off in one direction and talk. I don't dispute your figures about the value of ELV's. Some of us work for a balance, for Air Force to agree to eight shuttle missions a year, to help pay for that, but then, also, to develop CELV's, develop the Titan IV, to have a heavy lift capability that I have been talking about for several years in trying to get this administration's DOD to go on.

BALANCE NEEDED IN SPACE PROGRAM

We need a balance in this space program, and until some of you start getting off your own personal kicks, no matter how well founded that is, and getting together, because that is how the political process works, and that is how public opinion works in this country, and we are going to fail if we go off and do not have a balanced program.

We talked about commercialization. I happen to think if we never got a dime back in space from any direct commercial payment, the indirect spinoffs, how many lives we have saved from a pacemaker, from space research and development, more than 12,000 medical devices and/or procedures that have come mostly from unmanned flight. There is no doubt about it, but nevertheless, we don't spend enough on space in this country.

I disagree with those of you who say that our effort is adequate. It is totally inadequate considering the benefits that it could return regardless of which way we go or what the balance of those programs are. That is the political reality, and I am a politician and that is something that I know more about than you gentlemen do. Again, I am not competing with your scientific knowledge, but commercialization is unimportant to me.

SPACE BUDGET JUSTIFIED

Those people who made those predictions back in 1971 should have been more upfront. They should have said it is worth $7 or $8 or $9 billion dollars a year of government expenditures. What do we get back directly from building highways. The interstate highway system was supposed to be finished in 1972. The space shuttle will only be about 30 percent off in cost estimates in real dollars.

It is a lot better cost estimate than we made on the cost of the Congress of the United States, or the cost of homes or automobiles or anything else. I happen to think that we can justify the space budget on the basis of science and the other benefits that come from it without worrying about whether we get ITT and somebody else involved.

We spend a military budget in an enormous amount to defend the country. We don't expect to have the civilian sector help pay for it. This minuscule less than 1 percent of our total national budget, I would expect that scientists of all types, would be able to say, "We can justify that in the basis of what we learn."

Everyone of you has spent times in your lab, in your entire lifetime, spent a lot of money on nonproductive things that didn't turn out. That is fine with me because of the things that you have contributed that do turn out. There is waste and inefficiency in basic research and development.

I am sorry for the long speech, but you can tell I feel great frustration in all of these arguments, because we ought to have a vision of the future and what space research and development can do for all of mankind, and we ought to be willing to give a little bit on our own specific opinions of what it should be for a consensus and a balanced space program between ELV's and manned space flight.

If we can ever do that, maybe then we will start to reap the benefits. In the meantime, we are not going to go very far, because no program NASA comes up with is going to be liked and we will find a group of distinguished scientists who think it is lousy, and I don't happen to particularly like the current space station design either, that is not my point in defending it.

Thank you, Mr. Chairman.

Senator PROXMIRE. Thank you very much, Senator Garn.

We have another panel coming up and then we have the GAO after that, but I would like to give this panel, in view of the fact that Senator Garn feels so strongly about this and made such a moving statement, I would like to ask each member of the panel to respond briefly, maybe a minute or two, starting with Dr. Smith and going across.

RESPONSE TO SENATOR GARN

Dr. SMITH. I for one, would totally favor a balanced program. I think all of the space sciences ought to have the opportunity to conduct research and obtain meaningful results. There is no objection to that philosophy whatsoever.

I think the way to accomplish those kinds of things is to provide sufficient resources to guarantee that the various disciplines across the board have the opportunity to carry out those research programs, both involving the use of humans when appropriate, and ELV's and unmanned flights in other areas where appropriate.

Senator PROXMIRE. Thank you, sir. Of course, that is not our problem. This is an Appropriations Committee; technically we are not a policy committee. We decide how much money is going to be spent on these

programs, and those resources are very, very hard these days to come by.

Dr. Sagan?

Dr. SAGAN. Thank you.

Senator Garn, I felt from your remarks that perhaps we didn't explain as well as we should have what our concerns are. Let me try to just briefly respond to some of the points you made.

There is a finite federal budget. That means that we can't do everything.

ADEQUATE JUSTIFICATION SOUGHT

How do we decide what we should do and what we should not do? The idea of supporting manned space flight because at some future time it is possible that there will be a worthy return from it seems to me not the most effective way to spend a very restricted budget. We have to have adequate justification.

Senator GARN. Let me just interrupt you there, to go back to my point of, why should we expect a return? Why should we expect a commercial value?

Dr. SAGAN. I wasn't talking about commercial value, Senator Garn, I am talking about the entire spectrum of science, commerce, the intangibles, the pride in our accomplishment, cooperation with other nation's, anything you want to mention. If those are the justifications, they should be clearly laid out subject to critical scrutiny. Let's have the best path to those objectives that we can find. I think it does not follow that anything we do in space is OK. Some things are much more effective than others.

You mentioned a cartoon about a Conestoga wagon. Conestoga wagons were designed and effective at a time when the technology was not where it is right now, and so the idea that because unmanned exploration, instead of Lewis and Clark, made no sense in the time of Lewis and Clark, it doesn't follow from that that robotics and artificial intelligence to date can't do a much more cost effective and very efficient job in science and exploring the solar system and so on.

You mentioned something about education. Certainly, if Christa McAuliffe had flown and lived, she would have had some value in educating youngsters about some aspects of space. But, I think it still fair to ask: Is that the most effective way to educate youngsters about space or any other area?

On the issue of spinoff, yes, I think it is true that there have been some subsidiary benefits from NASA's manned and unmanned programs, but they are clearly so small as not to justify on economic grounds those efforts.

So, for example, the idea that the Apollo program was justified because of cardiac pacemakers, I don't think it makes much sense to spend $25 billion for sending men to the moon and NASA will throw in a free stickless frying pan, or a free cardiac pacemaker.

Senator GARN. No; you are making fun of what I have said, Dr. Sagan, because that was not my point. Certainly I agree with you on the Conastoga wagon.

I was trying to make a point for a balanced program. I think that is what Chairman Proxmire was wanting you to respond to. Do you believe in a balanced program?

I am not here saying we should send gee whiz men out there for any purpose. I did not say that and I don't want you to think I even indicated that. I thought it was rather a strong plea for a balanced program rather than going in one direction or another.

Do you agree with a balanced program?

Dr. SAGAN. The word balanced program covers a multitude of sins. The issue is what is the appropriate balance. That is an issue that can be discussed. There is an enormous spectrum of possible balances between manned and unmanned.

The only way to decide what is in the national interest is to decide what the goal of NASA is and then we can see whether manned or unmanned or an appropriate mix is the best way to do it.

One last remark: you said there was an enormous difference among scientists, in fact a very broad consensus in the scientific community on these issues. I would like to quote one sentence from Dr. Van Allen's testimony. He says, "I have no intrinsic opposition to manned flight, or to a manned space station, if their purposes are described honestly."

That is precisely the problem that most of us have, that a coherent justification for manned space flight has yet to be stated by NASA in a way that can be well defended. If there is such a justification, I think many of us would go along and support it.

The goal that I gather we share of manned exploration of Mars is such a coherent justification, but it has not yet been given.

Thank you very much for the opportunity to comment.

Senator PROXMIRE. Dr. Van Allen?

Dr. VAN ALLEN. I associate myself thoroughly with Dr. Sagan's remarks, and I was going to requote my own statement, which he saved me the trouble of doing.

HISTORICAL BIAS FOR ELV'S

Senator GARN. I understand your statement, Dr. Van Allen, but in reading your writings over the years, you do have an inherent bias against manned space flight in favor of ELV's, despite your very clear statement quoted by Dr. Sagan.

Dr. VAN ALLEN. The word "bias" is, of course, pejorative, Senator Garn. I am a critic of manned space flight. I am not an opponent. I hope I make that clear.

I personally keep a log of every manned flight by both the United States and the Soviet Union, persons involved, objectives of the mission, duration of the mission, what was accomplished. I keep a personal journal of that. I have a keen interest in these.

I join with you in the general statement of desiring to have a balanced program, but the question of what is the ratio that is desirable—and this is a point that Dr. Sagan just made as well—my position at the present time, my observation at the present time, is that the most

worthwhile aspects of our national space program are being murdered by excessive emphasis on the space station and on manned flight.

I think although it is balanced, the balance is entirely the wrong end up, and the balance I would like to see is 25 percent on manned flights and 75 percent on unmanned flights. At the present time the ratio is roughly the reverse and I think it is unjustifiably so.

Let me just finally cite, Mr. Chairman—I respect your injunction to be brief—during 1986, the Soviet Union had 91 space flights of which, as far as I can recall, only one was a manned flight. I believe that is a balanced program.

Thank you.

Senator PROXMIRE. Thank you.

Dr. Giacconi?

Dr. GIACCONI. I would like to associate myself to some of the comments made by my colleagues. I entirely sympathize with Senator Garn for his view of spiritual values of the space program and high vision for the future. I also agree with Senator Garn that there ought to be a balance between space science and manned exploration. The point is that such balance does not exist.

For instance, the decision of entirely flying signs on the shuttle has resulted in the following fact that we are spending a substantial amount of money for space science this year, more than $1.5 billion, and there are no flights.

Clearly, that situation is unbalanced, and I think—though I, in fact, support long-term exploration of the solar system by manned vehicles and establishment of colonies on Mars—I would like to see the space station to be a rational step along that goal.

I do not see it. I don't believe it is being designed the proper way, and I think that the unfounded claims that this is necessary to do science are to the detriment both from long-term manned exploration and of science.

The balance I see is a balanced program in which the two sides are independent and balanced.

Senator GARN. Mr. Chairman, can I make just one more comment?

I don't disagree with much of what has been said. Where we come to a disagreement is when you talk about $7.5 to $9 billion being an adequate amount of money out of a trillion dollar budget for the benefits to be gained from space flight.

I wouldn't even object, Dr. Van Allen, to a 75/25 unmanned versus manned. It would be fine with me as long as you don't take the 75/25 out of the $9 billion we are talking about now.

Let's not sacrifice manned flight. Let's try and have a coherent goal for what manned flight is supposed to accomplish, and increase the ELV's. I don't disagree. It has been unbalanced, not because the scientists in NASA or any place else wanted it that way.

BALANCE OF 75/25 REASONABLE

It has been a constraint imposed by Congress and OMB, and the choice was made to put more into manned flight, with those constraints. We would have very little disagreement, if we could have an adequate overall space flight budget. I think 75/25 would certainly be in the ball park of a reasonable balance.

Senator PROXMIRE. Thank you very much.

Thank you, gentlemen. You certainly have been a superlative panel. We deeply appreciate it. We are in your debt.

PANEL 2

We will now hear from our second panel composed of Dr. Bruce Murray, Dr. Peter Banks, and Dr. David Black.

Dr. Murray is a professor at Cal Tech and former director of the Jet Propulsion Laboratory; Dr. Banks is director of the Star Laboratory at Stanford University and former chairman of the Task Force on the Scientific Utilization of the Space Station; and Dr. David Black, NASA's Chief Space Station Scientist, who is going to be testifying on his own behalf.

Dr. Murray, go right ahead.

STATEMENT OF BRUCE MURRAY, PH.D., PROFESSOR, CAL TECH, AND FORMER DIRECTOR, JET PROPULSION LABORATORY

Mr. MURRAY. Thank you very much, Mr. Chairman.

I also appreciate very much an opportunity to speak to the committee. I would like to draw from our prepared statement, the one by Sagan, Murray, and Friedman [p. 16], and also add some additional and separate material, and try to focus a little bit on some of the issues that have been raised in the preceding testimonies.

In that regard, I thought Senator Garn's defense and exposition of the value of manned space flight, I agree with 100 percent. I will go further than my colleagues that I thought Christa McAuliffe's presence aboard the shuttle was justified.

MOTIVATIONAL PROBLEM

I spent 2 years, incidentally, personally trying to work an education in technology in that same period of time, and I realize that the problem is motivational, and that the President and the administration should use the available national political symbols to motivate. The fact that the President chose a teacher in space, I thought was very good and important.

My problem was not with her—it was a tragedy that she was killed. There was risk, and the risk was probably higher than most people appreciated, but everybody knew that it was risky. I think the issue in the case of *Challenger* might have been what were the rest of the people doing?

Launching a communication satellite certainly did not justify risking one's life. I think that the attempt to dramatize the importance of education did. So I think that we are probably pretty close together in that.

TRANSITION FROM EARTH TO MARS SOUGHT

Similarly, you and I and Carl, and a lot of people, really do believe going to Mars with humans is the right thing to do. So we are really very close to finding this consensus. Our frustration, frankly, personally, and to some extent with the planetary side, is the inability to find a way to link together with the government agency, NASA, that is supposed to be doing that.

NASA is still bogged down in Earth orbit; it is still struggling with post-*Challenger* reality. I think that we all have plenty of evidence of that. Somehow, we have to find a way together to cause this transition collectively, in the Congress and in the White House, to share and embrace this long-range goal of going to Mars, and then restructure in a constructive and effective way, programs that will meet the test of time in that regard.

That is why we are here. We are not here to criticize, to throw bricks, or otherwise try to weaken an already stressed agency.

Senator PROXMIRE. Dr. Murray, I apologize for interrupting. There is a rollcall on the floor. What I am going to suggest we do is, I am going to leave for about 7 or 8 minutes to run to the floor and vote, and come right back. Meanwhile, Senator Garn will chair the hearing, and we will have the questioning then.

Senator GARN. He will return so that I can go to the floor and vote.

Mr. MURRAY. In that case, I would like to pick up and deal with the issue, first, the need to rethink parts of the current station design. In that regard, I thought, since most of us are scientists here, and yet we are talking about the commercial benefits, it would be useful to involve a different opinion.

EXCERPTS FROM INTERNATIONAL SECURITY

I am going to read excerpts from a paper that was just published this spring in a journal called International Security. I will be glad to give the committee the information on it. It is by Dr. Albert Wheelan, entitled "A Born Again Space Program." Wheelan is the chairman and CEO of Hughes Aircraft Co. He is, therefore, in the commercial sector, very knowledgeable about space and certainly about the potential benefits of space processing.

I am quoting from the paper:

> Gradually, we want to establish long duration manned facilities in space possibly to learn how to send man to Mars and beyond. Such manned facilities would be very different from what is now proposed by NASA, and would be justified primarily by exploration, rather than other short-term goals.
>
> It is awkward to discuss the current NASA space station project because so much political capital has been spent on starting it. Before the program began, no government agency with a real job to do in space supported it.

He then goes on to say why, orbital incompatibility and other reasons:

> Against this combination of objectives, the proponents of the space station argue that a long duration zero G facility in space would make possible the manufacture of new

drugs and materials. This opportunity was presented as a potential commercialization of space, a popular theme at the time.

However, it ignored the enormously successful commercialization already happening through communication satellites, a billion dollar a year business financed by private capital. It ignored the fact that the only serious material processing space program had just been abandoned by the pharmaceutical house that cosponsored——

that was Johnson and Johnson in 1985.

That company instead turned to new genetic engineering technology that is becoming successful here on Earth.

It may be that we will learn how to make drugs and materials successfully in space. It may even prove economical to transport the necessary materials back and forth to lower orbit to do so. But this future promise does not justify a major commitment to space station now, nor does it support the predominant dedication of NASA to such an effort.

This is his concluding statement:

The present space station program is nothing more than a blind leap of faith. If we take this leap, almost nothing else will get done at NASA, our only agency for doing civilian space projects. An exclusive commitment to the space station would be even more tragic than our exclusive commitment to the space shuttle.

I introduce that because this is not a scientist, that is somebody who has the credentials in the area of commerce and technology, and that is his view.

MICROGRAVITY RESEARCH

I want to distinguish, and this is very important, the difference between materials processing as some kind of commercial process, which therefore requires a lot of power, and lot of commitment of the current space station, to zero gravity research, microgravity research, which is tremendously important.

None of us has any problem with microgravity research, and that clearly should be an important thing. There is an issue of how you best do it, and whether, for example, longer duration shuttle flights provide a very sound basis to carry out that kind of research, and a lot more of that, really, should be done before we commit large capital costs to the space station.

More importantly, we have to keep a balance. If it is research, we have to ask ourselves how much is this research worth compared to other research that this committee, for example, deals with. Twenty billion dollars, which is a number that is kicked around, including operational costs, and so forth, for the space station in this first phase that is being described here, is something like 10 to 15 years of the National Science Foundation budget.

So you have to ask yourself, is the research that is being carried out there really comparable in value to all NSF-supported research. I think that that is a tough question. I don't think it is. I don't think that you justify that much of a space station on those costs. You would settle on a more modest evolutionary program if you are really driving at research.

If it is materials processing, if there really isn't an economic basis to justify these large costs in terms of commercial return, then I think the

current station must rest on its research value in which case it is going to be harder to justify those same costs.

The way out of this dilemma is to embrace going to Mars with men, in which case there really is a justification, a national one like Apollo, that makes it worthwhile. Then the dilemma is that this station is not very well configured to support that stepping stone to Mars.

ADAPTING TO ZERO G

The particular point I want to make in that regard, which is discussed in the testimony, is that there has been a view of manned space flight from the beginning that the right strategy is for humans to adapt to zero G. Senator Garn is a good example of a person who has done this and has learned that it is possible. This has been the primary view of both the Soviet and the United States programs.

The Soviets went on a step-by-step program to lengthen the duration that it was possible to go. They got up to about 8 months and then they stopped, and that is significant. They didn't stop because they got tired or didn't want to. They wanted to qualify people for interplanetary flight and they couldn't.

I think we have to worry that it really may turn out that artificial G, let's say, a tenth G, whatever, something with a rotating system, really will be required. If that is the case, and if whatever space station we do is going to be a stepping stone to Mars, getting that kind of early data is going to be an essential part of it. We must know what it takes to go to Mars.

This is one of the reasons that we feel that the current space station is not optimized, that $20 billion is not very efficiently spent in going to Mars because it does not include, for example, humans in rotating systems at all, this is all considered as add-ons. I think that if one placed higher priority on that, the station would have a somewhat different configuration from the beginning.

Finally, then, mindful of the time of this hearing, we have to deal with what do you do about this. It is easy to criticize, as Senator Garn has said, but what do you do positively.

Senator GARN. Dr. Murray, excuse me for interrupting, but we will have to suspend. It means that if I don't play O.J. Simpson over to the Capitol, I will miss the vote. So just relax, chat, and Senator Proxmire will be on his way back. We will have a little recess until he gets back. Thank you very much.

[A brief recess was taken.]

Senator PROXMIRE. The subcommittee will come to order.

Gentlemen, I apologize for having to go to the floor. Dr. Murray, did you have a chance to complete your remarks?

Mr. MURRAY. No; we took a little rest break in the middle to allow Senator Garn, also, to have a chance to get to the floor.

Senator PROXMIRE. All right, go right ahead.

TESTIMONY REVIEWED

Mr. MURRAY. I had finished first endorsing, actually, many of the points that Senator Garn made in his previous comments, including that I felt that Christa McAuliffe's presence was very good because education is a high priority need in the use of manned space to reinforce, as a political tool. The leadership's desire to emphasize education is very good.

I raised the question: Having humans aboard *Challenger* to launch a communications satellite was a much more questionable use of humans in my view. I then went on to amplify a couple of criticisms, and I read a statement from Dr. Albert Wheelan, Chairman and CEO of Hughes Aircraft, about the space station, which gave strong lack of support to the idea of space processing as a commercial enterprise.

"WHAT IS THE RUSH?"

I am now at the point where I am just going to finish up and give a statement about what we should do about this problem, and I will do that from our text. The title of this is "What is the Rush?"

Today, the American space program is in shambles, despite generous funding for many years. The enormous past investment in the shuttle program, plus the large new investments required to restore it even to a minimally operational state, threaten the viability of the entire civil space program.

Funding a space station and timing its construction become critical to everything else NASA would like to do. How much will it cost? Why build it now? The goal of landing humans on Mars some time during the first quarter of the next century could provide a coherent and reasonably paced objective against which to match space station development and schedule.

A human mission to Mars will require the United States to develop new expendable launch vehicles, as will anything more than a rudimentary space station, to send precursor robotic missions, to research life support, and to develop life-supporting vehicles. A well-designed national program would address these requirements and see that they are carried out in parallel and at a reasonable pace, and that they meet the political and economic conditions imposed by the goal of exploring Mars.

It would also allow American space sciences to reverse their present decline. The Space and Earth Science Advisory Committee Task Force on Scientific Use of the Space Station recently told NASA that the space station should be reevaluated and reformulated or the United States could lose an entire generation of space scientists. That point, I am sure, will be developed by my colleague on the left here.

It is impossible to start a responsible space station program until the true payload capability, flight frequency, and, especially, cost per pound of cargo for the shuttle have been demonstrated, rather than overoptimistically guessed at, as has been the common NASA practice in the past.

NASA SCHEDULE QUESTIONED

It is true that NASA, with one slight exception, has never met the schedule that they proposed for the shuttle from 1978 to the present time. I, therefore, think that the burden of proof is on NASA, by experience, to demonstrate what the actual mature performance of the shuttle is.

The importance, for this discussion, is that the current NASA plan for the space station is very dependent upon both the cost and available frequency of the shuttle itself. They have not got a robust program of expendable launch vehicles that are carrying most of the cargo in their plan. For that reason, you cannot take the present plan at face value, except to the extent that you believe the present shuttle schedule. That has to be a matter of fact and experience, and not a projection.

Therefore, in the early 1990's, NASA must gain genuine experience and maturity in shuttle operations. In parallel, it can begin research soon on life support in space by lengthening shuttle missions from a few days to weeks. The shuttle can be used in this way for a broad array of experiments and activities.

Many scientists believe that it is more effective to use the shuttle as an experimental facility than as a "space truck." It may prove wiser to let the space station implementation wait for more appropriate expendable launch vehicles to become available, just as the Soviet successes with its Mir space station and other facets of manned space flight are built upon a solid foundation of routine expendable launch vehicle use.

You should note, as I am sure everybody knows, the Soviet program has got very routine expendable launch vehicles, the same ones they use for the manned program as he unmanned, the Proton launch vehicle. For the large unmanned programs and for all of the manned missions, the astronauts are carried on the smaller vehicle that is man-rated. They are using the same one all the time. It is a very conservative strategy. We should not ignore blindly that model in the design of our own program.

To conclude, then, we should take the time to do the job right. The failure to develop goals and programs consistent with post-Challenger reality, in my personal view, will put NASA on a road to disaster, and this time it will be terminal.

Thank you.

Senator PROXMIRE. Thank you very much, Dr. Murray. There is no question as to where you stand.

STATEMENT OF PETER M. BANKS, PROFESSOR OF ELECTRICAL ENGINEERING, STANFORD UNIVERSITY

Senator PROXMIRE. Dr. Banks.

Mr. BANKS. Thank you, Senator, for the opportunity to be here today. In view of the avalanche of potential topics provided by the previous panelists, I would like to ask that my written comments be submitted in full, for the record.

Senator PROXMIRE. I appreciate that.

Mr. BANKS. There is a potpourri of things to say, and I will go through these at several levels.

Perhaps first to say that my perspectives on this subject have been gained over the past 3 years as the chairman of the NASA Task Force on Scientific Uses of Space Station, the so-called TFSUSS. I apologize for this not being a euphonious acronym, but that is the way it is, and I will refer to it that way, for better or worse.

I should say that I am also an active space scientist. I participate in space research with the shuttle and ELV satellites, and I have served on NASA's Space and Earth Science Advisory Committee.

NEED FOR MAN-ASSISTED SPACE RESEARCH

I would like to read one statement that I think needs to come across very clearly to the committee here, and that is the scientific need for man-assisted space research and its support by a space station.

For 3 years, TFSUSS has probed the plans and needs of the various scientific disciplines involved in space research. Without exception, we find that all scientific disciplines can find important uses for human services in space and for the new facilities. The space station resources represent a means for greatly improving scientific research in space and enlarges our earlier capabilities based on the use of unmanned satellites in the space shuttle.

To that point, I would like to point out that the space station program as it is now constituted includes two important unmanned vehicles—the Polar platform and the so-called co-orbiting platform—in addition to the attached payload capability on the external members of the space station, as well as the activities to be included inside the space station.

This is a true synergistic interaction with the space science community. It hasn't been simply a case of going forward with commercial interests or, as I agree with the other panel members, the very improbable commercial activities, but it is a balance of activities in the science community that makes the current space station program a valuable one to this country.

With such benefits, you might think that it is perverse of me to be critical of the space station program as it now exists, but it is the case, and I have to tell you some of the reasons. I would also point out that these are not entirely agreed upon within my own committee, or within the scientific community at large. I will try to draw that distinction where it does apply.

Let me say that the plans for the space station were developed before the *Challenger* accident, by and large. In those days, the shuttle was the key vehicle for transportation into space, and the plans of the Office of Space Science and Applications were organized in a fairly good way to take account of this and provide a gradually increasing fraction of resource to man-assisted science activity, first with the shuttle, and then later with the 1992–93 space station.

FREQUENCY OF SPACE FLIGHTS

In fact, in 1985, the TFSUSS recommended that six space lab flights per year was a reasonable flight frequency in order to support the growth of man-assisted research prior to the availability of the space station. But as you well know, the situation since the *Challenger* accident is increasingly catastrophic for our national program of space science.

Prior to the accident, with NASA numbers, 76 equivalent shuttle science payloads were planned between fiscal year 1986 and 1995. By November of this past year, only 22 science payloads remained, and the total number of new space lab flights was reduced to just 3. That is quite a change.

So it is no exaggeration to say that the science that has been lost is devastating to this nation's program of space research, and it cuts across all disciplines, all institutions. This message is echoed by every major advisory panel of NASA, panels of the Academy of Sciences, and even independent professional organizations. Yet, to my mind, in a confusing way, the plans for implementing NASA's space station have gone forward independently of any consideration of a total plan of action which might improve the situation for space research, and especially for those attempting to use human resources in space.

While expendable launch vehicles may provide some relief for some users, a broader program of alternatives must be made available if we are to continue with a respectable program of research in space.

I have no doubt about the need for momentum in a project as large as the space station, but there are alternatives and I would like to discuss these with you.

You will notice that I am skipping over a portion of my discussion relating to costs. I am very concerned about costs and the impact they have upon space science, but I think this message has been communicated to this committee before. I think that it is a serious problem and one that needs to be taken into account.

ALTERNATIVES IN MANNED SPACE PROGRAM

Let me talk about alternatives because I have a feeling that it is the alternatives that are the primary focus of this discussion. I make these comments in the hope that Congress and NASA can work together to find a new way of incorporating new ameliorating elements into its manned space program.

For example, one way to do this, which has not been mentioned by my colleagues, is the possibility of accelerating the pace of development of the space station itself. I have no doubt about the value of the space station. What concerns me is the fact that it is coming late in the cycle of needs with respect to the space user community.

Previous testimony by the Associate Administrator for Space Station indicates that the principal difficulty with holding with the original plan for space station and a substantial early science capability is peak funding limitations set by OMB. This has pushed the program out at a time when the space research community is in serious difficulty. Therefore, I

have a personal feeling that something needs to be done to assist in this situation.

There are other alternatives, even if the space station must hold to its current schedule. I have talked privately, and not, as my colleague a few moments ago said, as a representative of TFSUSS, about the possibility of a heavy lift launch vehicle and the possibility of having a smaller, less capable space station, which could both reduce the number of shuttle flights to reach a state of development of manned space science, but also could reduce the heavy investments needed at the front end.

Personally, after a discussion with a number of colleagues, I think that that isn't a viable alternative. With the budgetary pressures facing us; in fact, if we had an opportunity to launch as early as 1992–93, our funding that I see coming from Congress or from the administration simply wouldn't handle the cost of the modules and the science ready in time for that flight.

COMPARISON OF UNITED STATES AND SOVIET PROGRAMS

Yet, in retrospect, if you look back at our policy toward space station since 1970, you see that we would have been, in fact, far better off if we had continued with our Saturn V engines and small space stations. The historical record is clear that we and the Russians began with their Salutes and our Skylabs at about the same time. They learned more slowly than we learned.

Our Skylab was far better than even, say, than Salute VI or Salute V. But with Salute VI and Salute VII, and the Mir station, the pressure of time began to show. Salute VI was the big motion forward in the biomedical sciences. Salute VII was their big push in microgravity sciences related to materials science, and materials processing.

There is no doubt in my mind that they are far ahead of us at the present time in those areas. In life science, as you have heard in previous testimony, it is absolutely essential if we are to be competitive or even collaborative in a joint mission to Mars in the early part of the next century.

I also have to take issue with my colleagues who, I think, are shooting at a red herring with respect to space industrialization. For the past 1½ years, probably since my committee, the TFSUSS, took a strong position on this, you have not heard much about space commercialization and industrialization, because the facts are relatively clear. What needs to be done is materials science and life science, and not commercial development. I think that you will see that the NASA view has shifted accordingly.

The fact is that we do need a national laboratory in space that keeps us at least up to date and current with the Russian capabilities. What is remarkable to me is the lack of injection of the Soviet experience in these discussions. Certainly, with the Salutes, with the Mir station, and whatever station they will have on orbit by 1995, when we are first appearing, they will have gained at least 10 years, perhaps 16 years of experience in these areas.

It is easy for colleagues in astronomy, in planetary observation, in solar/terrestrial, my own field, to discount the importance of having capable scientists in our country working on these problem. We cannot simply wait to receive basic data in the life sciences, nor in the materials sciences from the Russians. We have to be up there and operating.

Hence, perhaps you can understand my frustration at seeing the space station program which is marked on year by year, year by year, such that we are in the same position relative to space station as when I began my studies in 1984.

There are other alternatives, things that can be done that may be more practical than talking about advanced skylabs and heavy launch vehicles, and let me tell you what they are.

EXTENDED DURATION ORBITER

First, as my colleague by my right has just mentioned, a low-cost extended duration orbiter is probably the most dramatic way to double the science from the existing space lab flights. Yet, this proposal is more that a year old. It has been sitting in front of various offices within NASA, with inaction.

In fact, I understand that the latest action is to deny the usefulness of an extended duration orbiter. I think that this is wrong, and I think that the Congress and NASA need to get together and come to agreement to give us that capability in view of the lack of resources available to us.

INDUSTRIAL SPACE FACILITY

Second, private industry, in the form of the industrial space facility, is now a viable alternative for some types of man-tended capability. NASA is in the process of negotiating a memorandum of understanding space industries, and that should be accelerated, because that is a platform similar in many ways to the Cosmos module, and other capabilities of the Soviet fleet, which gives us an opportunity for medium-scale materials science activity.

It does not solve the problem of the life sciences. This question of how to satisfy the need for basic data on the long-term development reactions to humans to weightlessness. We can't do that without a long-term space station.

Let me also say that there are other programmable elements that I haven't heard mentioned. The large platforms in the space station program could be moved forward and ameliorate some of the difficulties in our current manifesting.

Some of these 50 payloads that have been dropped from the list could be brought back and given their proper place in the space flight view by moving the large platforms earlier in the program. Of course, you recognized that this is an unmanned part of the space station program.

USE OF SHUTTLE FOR SCIENCE AND SPACELABS

Finally, the increased priority for use of the shuttle for science and spacelabs would really have a dramatic impact. I am appalled, per-

sonally, by the fact that there are only three spacelabs currently manifested between now and the onset of the space station, whenever that may be.

That is simply wrong. It is taking away our ability to conduct the fundamental research that would support very import research in the area of life science and microgravity science. It simply takes it away and defers to some time in the future capability.

TFSUSS REPORT

While much of this is based on a factfinding, I must say that much of this is parallel to what the microgravity TFSUSS has said, and I would ask your permission to include in the record the written report from our most recent meeting of the TFSUSS where we give detailed discussion of these points I have made to you here.

Senator PROXMIRE. Without objection, so ordered.

[The report follows:]

CONCLUSIONS FROM THE SESAC TASK FORCE ON SCIENTIFIC USES OF SPACE STATION

Fact-Finding Meeting of March 19-20, 1987
Stanford University
Stanford, CA

March 30, 1987

Revised April 23, 1987

BACKGROUND

The TFSUSS is deeply concerned about the present and apparent future lack of sufficient space flight opportunities for all disciplines engaged in space research. On this topic we are in full agreement with the worries which have been expressed in recent months by many other NASA and National Academy of Sciences advisory committees. The crucial question of whether the federal government can commit itself to maintaining the excellence of the existing national space research program through the difficult post-Challenger era must be answered quickly through supportive actions rather than words. And, as a consequence of its magnitude and timing, the Space Station Program now lies at the crux of events: The possibility of recovering from our present difficulties in space research depends in large part upon the Space Station, both in terms of its timely availability in the next decade and the extent to which it is capable of providing suitable resources to the science and technology users.

The Challenger accident has exposed a great difficulty in our capability to support important manned and unmanned space research programs. A variety of new restrictions now indicate a significant lessening of Shuttle availability , dependability, and performance, even when a new Orbiter joins the fleet of existing vehicles in the early 1990's. The consequences of this diminished capability is readily apparent in the manifesting of NASA science and applications missions. Between 1988 and 1995 a NASA study[1] shows that even with a combined use of Space Shuttles and Expendable Launch Vehicles (ELV's), there will be a net reduction of science flights equivalent to 50 shuttle missions, as measured against plans in force before the Challenger accident. Of the identified 76 shuttle equivalent payloads planned before January, 1986, only 22 now remain verified in the schedules of the Office of Space Science and Applications. This situation is illustrated graphically in Fig. 1.

The more recent January, 1987 Mixed Fleet Study[2] from NASA's Office of Space Flight (OSF) indicates a more difficult situation. Even with a full fleet of STS Orbiters and currently available ELV's, OSF feels NASA will still be unable to meet its presently agreed upon commitment to all space users: Further reductions in the flight manifest are still necessary and it is likely that some further loss of science missions will result. The situation for manned science programs is espe-

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[1] Overview of Shuttle Payloads, Office of Space Science and Applications, NASA Headquarters, Washington, D.C., November, 1986.

[2] Report of the NASA Mixed Fleet Study Team, D.R. Branscome, Team Leader, Office of Space Flight, NASA Headquarters, Washington, D.C., January 12, 1987.

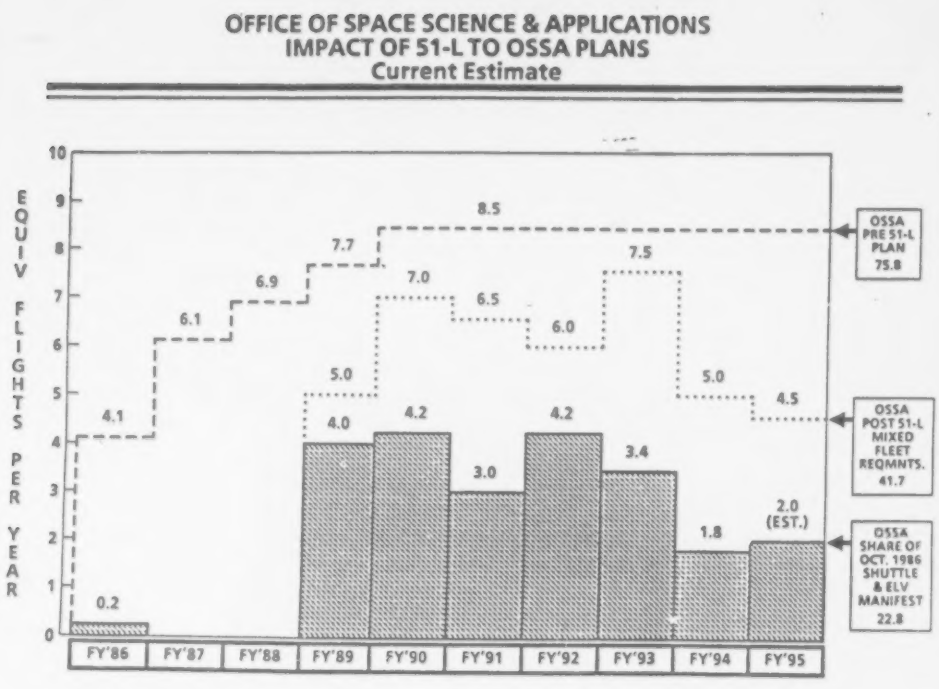

Figure 1. Office of Space Science and Applications; Impact of 51-L to OSSA Plans in the period FY'86 through FY'95.

cially grave: The OSF study concludes that manned science programs and contractor/civil service support will be reduced below pre-Challenger levels by more than 50% in the 1988-1995 time period and that most programs will be delayed by at least three years and likely much more.

The impact of this reduction of access to space can be more readily seen in terms of the list of specific space research missions which have been cancelled by NASA's Office of Space Science and Applications (OSSA). Figure 2, taken from a November, 1986 OSSA briefing document, identifies specific science projects which have been lost from the flight manifest over the period 1990 through 1995. (This list doesn't take into account the further reduction called for by the previously mentioned OSF Mixed Fleet Study[2].) The annual increase in the number of missions lost is striking and ample evidence of the severity of the problem facing science users of the STS system. Equally damaging is the more subtle fact that the manned science elements of this list are largely composed of flight activities which were originally proposed and accepted for flight in the late 1970's as part of the original Spacelab announcements of flight opportunity. Since that time there has been no general opportunity for soliciting new Space Shuttle-based science experiments which could build upon knowledge gained in the intervening decade of space research. Thus, the delayed and substantially reduced manned science of the first five years of the 1990's represents a backlog of ideas and capabilities efforts up to 15 years old. This is not a good situation.

OSSA PAYLOADS NOT ACCOMMODATED

FY 1989	FT 1990	FY 1991	FY 1992	FY 1993	FY 1994	FY 1995
		ASTRO-2 (S) LITE-1 (S) MSAT (S) SPARTAN-11 (S) WAMDII (S)	AFE (S) GRO REV-1 (S) IML-2 (S) MSL-10 (S) SPARTAN-4 (S) SPARTAN-7 (S) SRL-2 (S) STORE (S)	ASTRO-3 (S) ATLAS-3 (S) CLUSTER (LE) CRAF (E) HRSO-1 (S) LGCO (LS) MSL-11 (S) MSL-12 (S) SLS-3 (S) SPARTAN-8 (S) SPARTAN-10 (S) SSBUV-5 (S)	ATLAS-4 (S) GP-B (E) GRO REV-2 IML-3 (S) LAMBDA PT (S) MSL-13 (S) MSL-14 (S) SPARTAN-9 (S) SPARTAN-14 (S) SPL-1 (S) SRL-3 (S) SSBUV-6 (S) XTE (LS)	ATLAS-5 (S) AXAF (S) HRSO-2 (S) LYMAN ALPHA (S) MSL-15 (S) MSL-16 (S) SLS-4 (S) SMM-RETR (S)* SPARTAN-12 (S) SPARTAN-15 (S) SPL-2 (S) SSBUV-7 (S)

S = SHUTTLE E = ELV * AS EARLY AS POSSIBLE
LS = LEANING SHUTTLE LE = LEANING ELV

11/7/86

Figure2. OSSA Payloads not Accommodated: FY'89 through FY 1995.

With this background it seems clear that the present two year period of STS flight standdown is just an opening phase of a dramatic reduction in U.S. manned science activity which will continue until the Space Station is available for research work. Even when the STS is again in operation, its reduced flight schedule and large list of non-NASA users means that there will be few flight opportunities for the current community of science and technology researchers. Spacelabs, once the proud flagships of ESA and NASA manned space science, will no longer be an important element in the OSSA program: Present plans call for a total of three additional U.S. Spacelab modules (and three lesser capability igloo/pallet) missions between 1988 and 1994. The total number of Spacelab missions to be flown, including all users, will total no more than nine, if current plans are followed.

All NASA science disciplines are involved to some extent in manned science activities and these users will be seriously hurt by the lack of adequate transportation to space. Special mention should be made, however, of the impacts upon microgravity research, including materials science and technology and life science and solar-terrestrial studies. These disciplines require extensive human assistance in the conduct of their research. Indeed, one of the major thrusts of life sciences is biomedicine aimed at understanding all aspects of supporting humans safely and comfortably for long periods in space. (Such information is vital if this nation wishes to contemplate participation in manned planetary exploration with the Soviet Union in the next century.) Without

access to Space Shuttles and Spacelabs in the early 1990's, life science and materials science and technology cannot progress beyond rudimentary fundamentals, leaving the U.S. increasingly far behind the Soviet Union in these important research areas. And, without a timely Space Station, these disciplines may never be able to match the level of accomplishment now completely open to the Soviets.

Space Station represents an important step forward in manned space science. The TFSUSS has strongly supported the development of this large, multi-user facility and has played an important part in helping to define the various parts of the plan. All space science disciplines will benefit from the new resources offered by the pressurized modules, attached payload space, and the free-flying platforms. However, during the past year the schedule for development of the Space Station has been beset with difficulties deriving from STS transportation issues and higher than advertised costs. Nevertheless, through these confusing times the TFSUSS has anticipated Space Station as a possible, important means for alleviating the severe crisis in space experiment flight opportunities that will plague the first years of the 1990's. The combination of frequent STS flights to the core station, large laboratories for microgravity sciences, and substantial attached payload areas can combine to offer strong support to the U.S. and international space research community following the forthcoming years of reduced access to space.

From this perspective, the difficulty with Space Station plans has been in determining when valuable science can actually begin. One year ago the schedule for Space Station called for early science activities by mid-1994. Current Space Station plans, written in a more realistic atmosphere of budget constraints and STS availability, now aim at providing an initial research capability by 1996 with a strong capability developing later, perhaps in 1997. IOC itself may not occur until 1998. However, even this delayed schedule may prove to be too optimistic in the face of budget problems and dependance upon a relatively fragile STS transportation system. Furthermore, there is also concern within Congress and the traditional science disciplines about the value of man-assisted space research and the financial impact of Space Station development upon existing science programs. These concerns may impose more extensive delays or setbacks than is now realized.

The delays in putting Space Station into operation have a direct impact upon the conduct of manned space science. In the face of the space transportation crisis and with a lack of suitable interim capability manned or man-tended platforms, each year of delay in the arrival of Space Station means an additional year of enduring a withered space research program with weakened capability for continuing our former traditions of international excellence and leadership. If Space Station operations must wait until 1996, and if no serious alternatives for man-assisted space research are provided in the meantime, those members of this nation's space research community still active in their research work will have endured a full decade of enormous difficulty in attempting to pursue their studies. The TFSUSS foresees that the majority of current senior researchers will have drifted into other, more productive areas of technical work, an entire generation of younger scientists will have given up their work, and there will be no adequate pool of appropriately trained and motivated graduate students to resume a resurrected program of manned space research.

Meanwhile, the Soviet Union's Mir space station will continue to support a growing program of research. This year Mir will see the addition of two major research modules devoted to x-ray astronomy and to remote sensing. Before 1990 two more modules supporting life science investigations and materials research will be attached and put into operation. While the Mir is smaller and less capable than the planned U.S. station, the fact that it is now operational and that work is being supported by both Soviet and western European scientists should give this nation cause for great concern. Further developments are also pending. Engine tests of their shuttle-associated HLLV were reported last week, and it is apparent that their space shuttle/cargo carrier will permit major new space initiatives to be well underway long before the currently planned U.S. Space Station can begin any significant operations. For almost a decade into the future the U.S. must talk about its manned space station in terms of hopes and expectations, while the Soviets and their colleagues will be presenting facts and results from their own program.

RECOMMENDATIONS

It is with this background that the TFSUSS has come to agreement on the following statements.

1. Concerning Current Plans for Space Station.

The TFSUSS recognizes that the core Space Station, as it is currently conceived, provides a good match between engineering design and the technical requirements of the space research community. However, we note with deep regret that the current schedule for Space Station places use of these facilities beyond the operative horizons of the present generation of space scientists. Of necessity, members of the space research community must first deal with the severe reduction in man-assisted space research opportunities now impacting all U.S. space science and technology investigations.

We sincerely hope that this difficult period of reduced space research capability may end with the appearance of the Space Station. However, we are unable to be overly optimistic about this relief since the lack of an adequate space transportation system or budgetary difficulties may retard timely development of Space Station facilities beyond dates now thought reasonable. Consequently, the TFSUSS urges NASA, Congress, and all others concerned with the Space Station plans to recognize the singular importance of this manned facility to the U.S. program of space research and to take all possible steps to accelerate its development.

The TFSUSS realizes that options to accelerate deployment of a space station may require major changes in engineering or a greater early year fiscal commitment to the project than now seems to be acceptable. Nevertheless, as described in greater detail later, new options for building and putting in place portions of Space Station seem to be possible if this nation adopts plans leading to the timely arrival of a new, Shuttle-Derived Heavy Lift Launch Vehicle (HLLV). The TFSUSS strongly supports the recent statements of Mr. Dale Myers, NASA Deputy Administrator who, is

reported[3] to have advocated the use of an unmanned cargo carrier and HLLV in the Space Station Program during a Senate Budget Committee hearing. The TFSUSS agrees with this and is convinced that such a vehicle would help resolve many of the transportation issues surrounding development of the Space Station. It could also conceivably shorten the time needed to bring the facility into reasonable operation. Consequently, the TFSUSS urges that NASA undertake new space station architecture and development studies in parallel to the work already being done. The goal of this work should be to provide an alternative plan of development if the HLLV transportation option becomes possible in the next year.

The TFSUSS also feels that NASA has an obligation to the national research user community to develop interim facilities which can be used to improve this nation's capability for space research in the years prior to Space Station. We urge development of space facilities which can best support the traditional space science disciplines and aid the emerging microgravity sciences. Examples of such an approach include: (1) a return to extensive use of Spacelabs when flight opportunities arise and (2) the addition of an Extended Duration Orbiter capability to enhance the scientific return from existing shuttle missions. Further thought should also be given to the early development of multi-user, low inclination orbit platforms which could be used by all space science disciplines in the years prior to having an attached payload capability on the core Space Station. Finally, the use of free-flying, man-tended modules such as the Industrial Space Facility proposed for development by Space Industries, Inc. can provide an important, interim solution to having significant space research capabilities prior to Space Station operations.

2. Adequacy of Advanced Funding for Space Station Science.

The TFSUSS calls special attention to a major difficulty in current NASA planning with respect to funding of man-related scientific investigations. Present budget plans make no provision for advanced instrument or facility definition or development. Even if flight activities for Space Station are delayed until 1995 such a policy guarantees difficulties in mounting important science investigations. The omission of new funding for science instruments and facilities for Space Station can be compared with ignoring costs for furnishings and research equipment in the planning for a new science laboratory on a university campus. While different costs must be borne by different participants, there must be some timely, final plan for the new costs to be borne by supporters of the users of the facility. In this regard, Space Station is no different from construction of a new campus building. Adequate funds for the science must be identified and made available to users or the facility will not be able to function in support of science programs.

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[3] "NASA Deputy Endorses Heavy Lift Launch Vehicle", Aviation Week and Space Technology, March 23, 1987, p. 60.

3. A Special Message from TFSUSS Members Involved in Manned Space Science

A) There is a compelling requirement for a permanently manned Space Station for the microgravity sciences, including materials science and technology and life science, and solar-terrestrial physics, in order to:

- Qualify man for extended duration in space;

- Carry out interactive experiments in fundamental physics, biology, materials science, and provide intervention and observation support for space and earth observing instruments;

- Provide high power necessary for certain materials science experiments and development of commercial processes.

B) Experiment opportunities will be available with the Space Shuttle (with an EDO capability), the Industrial Space Facility, and additional Spacelab missions. Plans should be made to take advantage of these important interim steps to a fully resourced Space Station. However the IOC Space Station will be essential to provide the necessary resources (power, space, and time on orbit) to carry out the full microgravity program.

C) Funding for the development of microgravity, solar-terrestrial physics, and earth observations hardware for the Space Station is inadequate at this time to have instruments and equipment available to support the present (1995) Space Station schedule.

D) Funding for support of basic science from which future space experiments will come in all Space Station sciences must be increased in order to generate a healthy scientific program during the 30-year life of the Space Station.

4. Concerning the Heavy Lift Launch Vehicle (HLLV).

A) Even after science requirements have been reduced by over 50% from pre-Challenger plans, the maximum realistic number of ELV launches have been included, and 16 flights per year are assumed for the Space Shuttle Orbiter, there is still inadequate launch capability to meet NASA payload requirements[2]. At a more realistic level of 12 STS flights per year, the shortfall in mission capability equals 5 to 8 equivalent STS flights per year, comparable to the full requirements for NASA science on the Space Station.

B) The present plans for some 32 STS flights to reach Space Station Initial Operating Capability (IOC) are not considered by TFSUSS to be a reasonable plan for Space Station emplacement. First, it requires too many sequentially successful flights to maintain a high

probability of success. Even partial success (far short of a catastrophe) can produce large delays in successive station emplacement missions. Second, threats of cost overruns or factors other than mission failure (such as the recent rumored two part funding agreement for the Space Station Program) can also lead to long delays in reaching a sufficient level of research capability with the Permanently Manned Configuration (PMC) and IOC. Based on what has been said previously, if the plan is to reach PMC by 1995/96 the support of the science community for the current Space Station will likely be weak.

Touching on items mentioned in the initial paragraphs of this report, even with a perfect launch performance of STS for Space Station, the shortfall in launch capability beyond 1992 will essentially wipe out all of the manned space science activities of NASA beyond this date. (The OSSA information of Figure 2 predates the more realistic data of the OSF Mixed Fleet Study[2].) The TFSUSS considers this situation to be completely unacceptable to the science community.

C) As in our previous reports to NASA, we recommend again that NASA, while continuing their current design studies, promptly undertake parallel studies leading to evaluation of the development of a Heavy Lift Launch Vehicle similar in capability and function to that described in NASA's Heavy Lift Launch Vehicle Utilization study[4]. We strongly support the idea given in this report that the HLLV should be a Shuttle Derived Vehicle (SDV)to: (a) make maximum use of the long development of flight experience gained in the Shuttle program, (b) to made maximum use of the additional confidence and experience gained in post-Challenger redesign (other than Orbiter elements), and (c) to assure a development time to first flight of about 3 years, as indicated in the press by several major aerospace contractors (one of whom made a formal presentation to TFSUSS at its October, 1986 meeting).

D) Three options for Space Station emplacement have been considered. The option numbers correspond to those of the NASA HLLV study [3], with minor modification of the option design as described below:

Option 1: Maintain the module diameter at about 14", but use STS transportation through PMC,

Option 4: Maintain the module diameter at about 14' to retain STS compatibility, but plan to launch all pressurized modules (and nodes) in an integrated, fully ground outfitted, racetrack mode with an HLLV.

Option 4A: (slight modification) Combine laboratory and habitation modules into a single, large diameter cylinder with two separate segments. Each segment is separately

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[4] Space Station Heavy Lift Launch Vehicle Utilization Study Results, W. Ray Hook, Team Leader, Presentation to Dale D. Myers, NASA Deputy Administrator, NASA Headquarters, Washington, D.C., January 13, 1987.

pressurizable, contains comparable facilities, and provides full safe haven capability. This option could also examine multiple modules (separate lab and hab) but of diameters larger than 14', thereby necessitating HLLV launch.

Even if dual compatibility between STS and the HLLV is maintained (Options 1 and 4), we can see no reasonable circumstances to select Option 1 (STS deployment) instead of Option 4 (HLLV deployment) after the successful development of the HLLV.

When the HLLV development is undertaken, we believe it is an acceptably low risk to assume that it will be successful. To then select STS deployment is highly undesirable to the science community because:

- It consumes too many STS flights, which should be used to meet other science requirements,

- It would take too long, moving PMC too far into the future such that the Space Station couldn't meet the more immediate needs of research users,

- The numerous STS flights involve more program risk than the smaller number of (HLLV+STS) flights.

After HLLV development has begun, we find Options 4 and 4A both tenable. We note with interest that Option 4 allows NASA to progress with current architectural plans for the modules and major systems. However, Option 4A is interesting because it provides a much larger volume for growth and storage than is the case for the smaller modules. Along these lines, the TFSUSS has noted previously that Space Station I volume need not be filled at PMC, or even IOC. This last option also appears to have better safe-haven capability, and might be less expensive to produce with a single contractor. However, the TFSUSS realizes that many different factors will influence the final decision about the station-architecture.

E) In view of the foregoing, we suggest that NASA promptly direct contractors to examine Options 4 and 4 A (as slightly modified) as a part of their Phase C activities. Then, at a time approximately 1 year from now, at or near the Preliminary Design Review, it can be verified that HLLV development has been initiated and the appropriate option can be implemented.

Should Option 1 be selected because the HLLV development has not been initiated, the penalty to the space science community will be severe, both in terms of opportunities delayed, and for the higher risks involving STS success and total costs to NASA.

5. Space Station Operations Studies.

The TFSUSS has reviewed the science operations planning of the Operations Task Force and is encouraged that this work is in the best interests of optimizing scientific return from the Space Station. The Operations Task Force has accomplished much for the benefit of the eventual science and application users in a remarkably short time.

Of particular importance to the future utility of the station is the way users can interact with the management in all aspects of experiment planning and operation. The TFSUSS is convinced that the proposed Discipline Operations Center approach to be a key element of the concept which should be brought into play in advanced utilization planning, pre-mission planning, flight operations, and post-experiment cooperative data analysis.

The TFSUSS recognizes that operations could be divided by station element as well as by science discipline. The TFSUSS strongly recommends that the Discipline Operations Center approach should be the desired outcome of the international negotiations. The concept of regional operations facilities, which can be made up of both Discipline Operations Centers and Station Engineering Support Centers, serve as a compromise solution to meet both science and political needs.

The TFSUSS further recommends that the user operations centers, including the POIC, should be funded and operated by a coordinated effort of the various national and international user organizations.

It is also our conclusion that the proposed decision-making process for investigator selection and flight seems unnecessarily lengthy. The TFSUSS recommends that this process be re-examined with the idea of streamlining the procedures to facilitate an easier consensus among the participating organizations and a consequent smoother path of involvement by the users.

We also note with concern that the TFSUSS has previously recommended that the Space Station Program (OSS) should establish a formal mechanism for interactive investigator involvement in the Phase C/D Space Station activities. The PSC RFP and the draft work package RFP's have not provided such a mechanism. This has a serious impact on the ability of the OSSA telescience testbed program to adequately interface and impact the Space Station design and development. Thus, we recommend again that OSS give vigorous support to the OSSA telescience testbed program, which must be regarded by all concerned as being fundamental to successful utilization of Space Station.

Mr. BANKS. Second, we have, of course, given this advice in written form to NASA. I wouldn't try to convince you that it has been taken, but it does exist, and I would like to have copies of those letters put in your record also for your perusal.

Senator PROXMIRE. That will be done.

[The letters follow:]

COLLECTED LETTERS

SESAC

TASK FORCE ON SCIENTIFIC USES OF SPACE STATION

APRIL 23,1987

SPACE, TELECOMMUNICATIONS AND RADIOSCIENCE LABORATORY

March 30, 1987

Dr. Burton I. Edelson
Associate Administrator for Space Science and Applications
Code E
NASA Headquarters
Washington, D.C. 20546

Dear Burt,

The SESAC Task Force on Scientific Uses of Space Station held a fact-finding meeting March 19-20, 1987 at Stanford University. The detailed results are included as an addendum to this letter.

The issues regarding effective scientific use of Space Station are becoming increasingly clear: (1) The Challenger accident has dealt a savage blow to plans for space science and particularly those related to the use of human resources in space, (2) The Space Station, while meeting the technical facility requirements of the scientific community, is too late to be of significant help to the science community who must endure 10 years (1986-1996) of greatly diminished access to adequate manned space facilities, (3) Funds to carry out the initial designs for Space Station science instruments and construction of important facilities are grievously lacking from current NASA plans, putting timely, effective scientific use of the 1996 Space Station into doubt, (4) There is a possible better path to achieve a Space Station if NASA can commit to a Heavy Lift Launch Vehicle in the next year or so. and (5) Interim facilities to support manned space science in the early 1990's are essential to maintain even a modest scientific program. Details of these can be found in the addendum.

We also were given the results of the Code S Operations Task Force studies. In these, the TFSUSS was very pleased. This group has accomplished much in its relatively short lifetime, and we commend their work to you in hopes that you will give them the support they need in various areas of contention, especially with respect to adoption of a scientific discipline orientation for user participation.

The TFSUSS sends you its collective best wishes on the eve of your departure for other responsibilities within NASA and elsewhere. We have appreciated working with you over the past three years. It was your close attention to the TFSUSS that made it possible for the science community to have a significant voice in the Space Station program.

Sincerely yours,

Peter

Peter M. Banks, Chairman
TFSUSS

SPACE, TELECOMMUNICATIONS AND RADIOSCIENCE LABORATORY

November 24, 1986

Dr. Burton I. Edelson
Associate Administrator for Space Science and Applications
Code E
NASA Headquarters
Washington, D.C. 20546

Dear Burt,

This letter brings you the results from the October 15-17, 1986 meeting of the SESAC Task Force on Scientific Uses of Space Station at Key Largo, Florida. The meeting was attended by most of the members of the TFSUSS and a strong contingent of NASA personnel from field centers and Headquarters. One of the important flavors pervading the sessions was an enhanced clarity of understanding by the members of the basic issues surrounding the successful use of space station for scientific purposes. Our discussions along these lines were aided by the helpful presence of NASA senior staff, including Jeff Rosendahl, Dick Sade, and Sam Keller from Code E and others from Code S, including Andy Stofan. We regreted not being able to meet with you, but realized the urgency of personal matters that kept you away at the last minute.

As in the past, the results of our meeting are presented in a separate report included with this letter. Five topics deserve special attention, however, since they are fundamental to space science and applications and the whole issue of space station utilization. These topics can be summarized as: (1) Program development, (2) Funding, (3) Preparations for space station, (4) Space Transportation, and (5) Foreign participation.

Before passing to these, it is important to state clearly that the TFSUSS sees great potential benefits accruing to space science from the Space Station Program. Our concerns, as reflected here and in other previous letters and discussions, arise not from our simple evaluation of this benefit, but from our responsibilities expressed in terms of a larger equation which tries to balance our belief in the future value use of these facilities for broadening the base of endeavor in the space sciences with the practical evaluation of the impact such an addition will have upon the pursuit of Code E's current science and applications programs. By doing so we strive to maintain our reputation for critical evaluation rather than program advocacy.

With this affirmation of general support for the potentiality of space station programs, let me turn to our specific concerns as they emerged at Key Largo.

With respect to program development, the TFSUSS comes away from Key Largo with the impression that the Code S plans for station development are rapidly outstripping Code E's efforts to define the envelope of scientific utilization. We see this in several ways. First, the changes in station capabilities related to the CETF assembly sequence options and the long time now needed to reach IOC have not been fully explored in terms of potential science opportunities, and we detect a reluctance on the part of Code E discipline leaders to become involved the intense, cooperative planning that is required to adequately utilize the resources which will gradually become available during space station assembly. Second, the current Code S Operations Task Force is now attacking problems of crucial concern to the scientific users, and Code E has yet to take an active

part in pursuing its interests relevant to this study. Unless Code E does so, it is likely that important decisions about science plans and capabilities may be made through default by Code S and its supporting contractors.

For these reasons, the TFSUSS wishes to strongly support enhanced OSSA space station work related to space station planning. The concept of a new Space Station Integration Office within OSSA seems to be an important way to make rapid progress in this direction. Such an organization would be able to focus OSSA's interests in space station by responding to the myriad of space station design and development activities now underway under the direction of Code S.

The second issue is funding. The TFSUSS is deeply concerned about the lack of funds to enter into initial space station instrument definition and other planning in FY-88 and worries that this will have serious repercussions upon the effective science utilization of the space station accommodations. The general problem, however, is that there are insufficient funds within OSSA to support the space station activities as an add-on to the current programs of space research. This is an agency problem which must be addressed by the Administrator and his staff. We strongly support actions you may take towards remedying this difficult situation.

The TFSUSS also believes that it will be necessary to have a readily identifiable wedge of new funding specifically set aside for space station activities. The option of allowing disciplines to enter into space station science definition and instrument development using only current funding is not viable in the face of science needs, especially for those activities relating to microgravity sciences (life science, materials research, physics and chemistry in space) and Earth Sciences.

The third topic is preparations for space station. Space Station represents a major commitment for scientific activities connected to our manned space flight program. All scientific disciplines can benefit from the presence of human resources in space, but in different ways where we possess little practical experience. Shuttle science payloads and Spacelabs are an important part of preparing to use the space station, and the TFSUSS is on record as supporting an enhanced program of preparatory science activities using these facilities. Unfortunately, the STS transportation situation demands a reduction in these preparatory endeavors. The TFSUSS supports your attempts to obtain more STS flights for the benefit of space science and especially those which will lead to experiments where the interactions between the space crews and the scientific equipment are fundamental.

Along these lines, we wish to call attention to an earlier recommendation from TFSUSS: That OSSA push strongly for an extended duration capability for the space shuttle Orbiter in order to enhance the scientific return from each of the scientific flights of STS. We continue to support this concept and urge you to take the initiative to insure that such a capability is developed in the near future.

In a similar vein, the OSSA concept of developing testbeds for exploring the value of telescience activities in various scientific disciplines is very important. Science activity in space needs the full capabilities of a modern communications system which will support a variety of scientific information transfer modes (voice, video, data) between remote users, NASA centers, and space-based resources. The OSSA testbed plans will enable evaluation of telescience requirements for the various disciplines at a time when space station systems and protocols can still be altered to support them.

The fourth issue is that of space transportation. The current space station plans are hostage to the uncertain capabilities and availability of STS. As noted above, this has grave implications for all of space science and, in particular, for the program of preparatory manned science activity which is important to the effective use of the space station. At the present time we are experiencing a difficult transportation "gap" which curtails all aspects of space science and especially that which pertains to the development of scientific activity connected to human resources in space. Unfortunately, even after the STS fleet is operating again, we forsee the possibility of a second "gap" which may have equally severe consequences to space science. This will arise in the

years of space station assembly (1993-1994 or longer) when the resources of the STS fleet will be directed towards constructing the space station. During the second "gap", the competition for STS payload space will be very intense, and it is likely that manned space science experiments like Spacelab will not be flown . Thus, just on the eve of space station activities there will be another one or two year hiatus in STS science flight activities which will certainly have a severe impact on those disciplines preparing to use the space station, including both the pressurized modules and the attached payload facilities. At the present time we have no solutions to this problem other than to note that such a situation would not arise if other unmanned vehicles were available for appropriate space station assembly missions. The introduction of a new MLV/HLV vehicle could do much to relieve pressures on STS and provide flight opportunities for the needed space science missions which depend on STS.

Finally, I must mention the topic of foreign participation in space station science utilization. The international plans for space station have opened the way to the possibility of important collaborations with the international science community. Members of the TFSUSS are in frequent contact with representatives from ESA, Canada, and Japan for the purpose of exploring space station collaborations as they pertain to different disciplines. The TFSUSS feels that it is important for OSSA to take action with respect to defining the modes of foreign science participation according to the needs of the U.S. scientific community. The results must then be given to Code S and other NASA offices to stand with other international agreements that are now being negotiated. Without such information, the TFSUSS fears that NASA may enter into specific agreements that may hinder and reduce the scientific productivity of the space station facilities.

The above topics are the most important issues to come from the Key Largo meeting. Other recommendations and general discussion having applicability to a variety of topics are given in the attached TFSUSS report. We would, of course, be happy to discuss these with you or your staff at greater length.

Sincerely yours,

Peter Banks

Peter M. Banks, Chairman
SESAC Task Force on Scientific Uses of Space Station

SPACE, TELECOMMUNICATIONS AND RADIOSCIENCE LABORATORY

March 30, 1987

Dr. Andrew J. Stofan
Associate Administrator for Space Station
Code S
NASA Headquarters
Washington, D.C. 20546

Dear Andy

The SESAC Task Force on Scientific Uses of Space Station held a fact-finding meeting March 19-20, 1987 at Stanford University. The detailed results are included as an addendum to this letter.

The issues regarding effective scientific use of Space Station are becoming increasingly clear: (1) The Challenger accident has dealt a savage blow to plans for space science and particularly those related to the use of human resources in space, (2) The Space Station, while meeting the technical facility requirements of the scientific community, is too late to be of significant help to the science community who must endure 10 years (1986-1996) of greatly diminished access to adequate manned space facilities, (3) Funds to carry out the initial designs for Space Station science instruments and construction of important facilities are grievously lacking from current NASA plans, putting timely, effective scientific use of the 1996 Space Station into doubt, (4) There is a possible better path to achieve a Space Station if NASA can commit to a Heavy Lift Launch Vehicle in the next year or so, and (5) The TFSUSS also supports the development of other, interim space facilities to support a modest level of manned space-related science activity in advance of the arrival of Space Station.

We also were given the results of the Code S Operations Task Force studies. In these, the TFSUSS was very pleased. This group has accomplished much in its relatively short lifetime, and we commend their work to you in hopes that you will give them the support they need in various areas of contention, especially with respect to adoption of a scientific discipline orientation for user participation.

The TFSUSS wouuld like to send you its appreciation concerning your personal support for the international science meetings. In the long term, such international connections will be of crucial importance to the success of the facilities, and early planning with all involved is a good way to establish a positive user environment.

Sincerely yours,

Peter

Peter M. Banks, Chairman
TFSUSS

PREPARED STATEMENT

Mr. BANKS. In summary, in closing, I think I have covered the fact that we are seeking—Senator Garn, I am sorry that you didn't hear my comments on the TFSUSS—a balanced program.

Senator GARN. I will read them on the airplane to Salt Lake City this afternoon.

Mr. BANKS. I hope that they can keep you awake, sir.

That concludes my testimony.

Senator PROXMIRE. Thank you, Dr. Banks.

[The statement follows:]

STATEMENT OF PETER M. BANKS, PROFESSOR OF ELECTRICAL ENGINEERING, STANFORD UNIVERSITY

Mr. Chairman and Members of the Subcommittee;

I appreciate the opportunity to discuss with you various aspects of the U.S. Space Station program. My perspectives have been gained over the past three years as Chairman of the NASA Task Force on Scientific Uses of Space Station (The so-called TFSUSS). I am also an active participant in NASA's program of space research using the Space Shuttle and serve on NASA's Space and Earth Science Advisory Committee.

The present public debate about NASA's Space Station program involves many complex issues. These include:

a) Concern about the unexpectedly high acquisition cost of the new facilities and how to accommodate these in a period of budgetary restraint,

b) Concern about the stress the Space Station Program will place upon NASA's research programs,

c) The value of the Space Station to our national and international collaborative programs of space research, and

d) Uncertainty about our national goals in space.

I would like to begin with a strong statement about the scientific need for man-assisted space research and its support via a space station. For three years the Task Force has probed the plans and needs of the various scientific disciplines involved in space research. Without exception, we find that all scientific disciplines can find important uses for human services in space and the new facilities. Space Station resources represent a means for greatly improving scientific research in space and enlarges our earlier capabilities based on the use of unmanned satellites and the Space Shuttle.

With such benefits, you might think it perverse of the space science community to be critical of NASA's Space Station Program. Nevertheless, this is the case and I would like to tell you some of the reasons.

The plans for the present Space Station were largely developed before the Challenger accident. In those days, the Shuttle was the key vehicle for transportation for space and the plans of NASA's Office of Space Science and Applications were organized to provide a gradually increasing fraction of resource to man-assisted science activity , first with the Shuttle and later, the 1992/1993 Space

Station. Indeed, in the summer of 1985 the TFSUSS recommended that six Spacelab flights per year was a reasonable flight frequency to support growth in man-assisted research prior to use of the Space Station. There were also some concerns about adequate funds to cover the added costs of the new research activities, but like translating a long sentence in German, we were willing to wait until the final action verbs at the end of the sentence before passing judgment about whether such funds would be adequate.

The situation since the Challenger accident has become increasingly catastrophic for our national program of space science. Prior to the accident a total of 76 equivalent shuttle science payloads were planned between FY'86 and FY'95. By November, 1986 only 22 science payloads remained and the total number of new U.S. Spacelab flights was reduced to just 3.

Members of the Committee: It is no exageration to say that the science that has been lost is devastating to this nation's program of space research and it cuts across all disciplines and institutions. The message has been echoed by every major advisory committee of NASA , panels of the U.S. Academy of Sciences, and many independent professional organizations. This reduction in level of effort of space research strikes at the heart of our ability to continue first rate scientific programs and seriously harms this nation's ability to attract and train scientists and engineers needed in the future.

Yet, plans for implementing the NASA's Space Station have gone forward independently of any consideration of a total plan of action which might improve the situation for space researchers, and especially for those attempting to use human resources in space. While Expendable Launch Vehicles may provide some relief for some users, a broader program of alternatives must be made available if we are to continue with a respectable national program of research in space. There is no doubt about the need for momentum in a project as large and as comprehensive as that of Space Station. Nevertheless, to those of us outside NASA there appear to be a number of compromises involving the plans for Space Station and other NASA flight capabilities which, if implemented could lead us through a most difficult time. I will return to these alternatives in a few moments.

A second concern about the plans for Space Station is escalating costs. The previously agreed upon $8 billion limit for putting Space Station into operation has been demonstrated to be too low by a significant margin and new expenses, such as NASA field center operations and space transportation expenses, have been added to yield much larger estimates. These, in turn, have resulted in substantially later dates for beginning science operations. Perhaps as importantly, the current plans for Space Station make no provision for the costs of designing, building, testing and operating all of the scientific instruments and other facilities which, after all, are the purpose of building the facility . It would not be unreasonable, for example, to find that an additional investment of $3 to 5 billion in science-related activities will be needed to put the Space Station into productive operation.

The implication of no cost planning for science for the Space Station is clear to all participants in space research: Unless adequate, new funds are obtained, the Space Station will inevitably impose great hardship upon existing and planned highly meritorious projects. The space science

projects already planned for the next decade are of excellent quality. They are already pruned to far less in number and diversity than is requested and justified by the scientific disciplines. If funding for the new Space Station is diverted from these projects, there must inevitably be a decline in productivity and quality across all disciplines. This erosion the existing program of space research would inevitably reduce the number of investigator groups across the country and extend the time between space missions to the point where stable investigative groups outside of NASA will no longer exist.

The TFSUSS has repeatedly brought this Space Station funding problem to the attention of NASA and the Office of Space Science and Applications, but there has been no response. No significant funds have been planned for conceptual designs of new scientific facilities, no plans have been made for funding of expensive, new instruments and experiments.

My closing comments return to the question of alternatives. They are made in the hope that NASA and Congress will work together to find a way of incorporating new , ameliorating elements into its manned space program in support of space research. This could be done, for example, by accelerating the pace of development of the Space Station itself. Previous testimony by the Associate Administrator for Space Station, for example, indicates that the principal difficulty with holding to the original plan for a substantial early science capability in 1994 is a peak funding limitation set by OMB. There is great benefit to this country in keeping this original schedule and I would urge that the increase in funds involved be regarded as an important step towards reaping the rewards of new knowledge made possible with the Space Station.

Other alternatives also exist if the Space Station must hold to its current schedule. According to the NASA Deputy Administrator, the use of a Heavy Lift Launch Vehicle would permit a rapid deployment and greatly reduce the number of Shuttle flights required to reach a particular state of operation. Additionally, one could think of the possibility of a space station of lesser initial capability appearing in the early 1990's which might grow according to user needs over the following five years.

Other important, and perhaps more practical things can be done to improve our ability to use alternate facilities before Space Station is available. First, a low-cost Extended Duration Orbiter can more than double the science yield of a Shuttle flight. The proposal to go ahead with this innovation has been in front of NASA for more than a year and the TFSUSS strongly supports its development.

Second, the use of the Industrial Space Facility now being offered by Space Industries may provide an interim man-tended capability to help with fundamental microgravity and other studies prior to using Space Station. This opportunity , also strongly supported by TFSUSS, should be encouraged.

Third, it is also possible to reschedule one or more of the large platforms included in the Space Station Program. This could either accelerate present plans or serve as a stop-gap, new capability to serve as a multi-experiment platform to ease the current experiment manifest.

Finally, increased priority for use of the Shuttle could improve the number of Spacelabs and Shuttle flights available to the science community. This alternative comes with a need for increased funding for Shuttle science missions, but in the long run this investment can be viewed as the opening wedge of funding needed to support the later Space Station science operations.

Mr. Chairman. My presentation to this point has been based upon a recent fact-finding meeting of the Task Force on Scientific Uses of Space Station. In order to make this detailed information available to this committee and others, I would request your permission to include the TFSUSS written report in the record of this hearing. Furthermore, for the benefit of this committee, I would also request permission to enter into the record copies of TFSUSS advice provided to NASA over the past six months. This correspondence provides an important background to the current discussions.

This concludes my testimony. Thank you again for the opportunity to appear today.

LETTER FROM SENATOR PROXMIRE

MAY 4, 1987.

DR. PETER M. BANKS,
Director, Star Laboratory/SERA
Stanford, CA.

DEAR DR. BANKS: It was a pleasure to receive your testimony at Friday's hearing on the proposed space station.

Following is a question that Senator D'Amato has requested you answer in writing for inclusion in the published hearing record:

"The Task Force on Scientific Uses of the Space Station has recommended that NASA strongly consider the development of a heavy-lift launch vehicle.

If these heavy-lift vehicles were developed, would the resulting added launch capability have any implications for the current design of the space station's habitation and laboratory modules (i.e., would HLLV's permit the launching of larger modules with greater potential for scientific activities)?"

It would be helpful if you would answer the question within the next 30 days and return it typed on the enclosed blue-line paper according to the attached instructions to the subcommittee office, SD–142, Senate Dirksen Office Building, Washington, DC 20510.

Thanks once again for presenting your views at today's hearing.

Sincerely,

WILLIAM PROXMIRE,
Chairman.

QUESTION SUBMITTED BY SENATOR D'AMATO

Question. The Task Force on Scientific Uses of the Space Station has recommended that NASA strongly consider the development of a heavy-lift launch vehicle. If these heavy-lift vehicles were developed, would the resulting added launch capability have any implications for the current design of the space station's habitation and laboratory modules (i.e., would HLLV's permit the launching of larger modules with greater potential for scientific activities)?

Answer. It is possible that single modules larger than are now planned could be placed on orbit with a heavy-lift launch vehicle. However, it is probably more practical to use an HLLV to launch clusters of the presently designed modules. Advantages of this would be the opportunity to use current designs (which saves time and money) and to outfit and test most of the laboratory facilities on the ground before flight. The current STS plan, for example, relies on attaching modules to each other on orbit and in addition, to substantial on-orbit outfitting. This extra effort could be almost completely avoided through use of an HLLV.

My personal suggestion that an HLLV be used to launch a single, large structure was based on the hope that the United States could develop space station facilities substantially earlier than is now the case. In fact, NASA has looked at a variety of possibilities of using an HLLV for space station and, in my opinion, the possibility of using the existing modules already outfitted and linked together is superior from a technical point of view. Of course, if there is no money to build modules early, than the advantage of an HLLV must accrue as a consequence of its ability to reduce the required number of STS flights to achieve an operating space station.

STATEMENT OF DAVID BLACK, CHIEF SPACE STATION SCIENTIST, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Senator PROXMIRE. Dr. Black.

Mr. BLACK. Thank you, Mr. Chairman, and other members of the committee.

I feel a bit like the individual walking behind the circus parade of elephants with a broom and bucket, being last in this parade.

I don't have any prepared remarks, Mr. Senator, let me just, in a sense, respond to some of the issues as I see them.

I think I would like to build a bit upon what Senator Garn said. I think, as an astrophysicist and planetary scientist myself, I think what you see in the reaction of my colleagues today is a great sense of frustration at the health of the national space program, and view in this, as they view the space station, essentially, the parable of the blind in describing the elephant, to return to the elephant, if I may, and that is that each of us in our own discipline and narrow point of view, as we look at a device like the space station, tends to describe it and perceive it in the way that best suits or deals with our own particular discipline.

In the case of planetary, at least at first blush, it would appear that there is not much to be gained from the space station. I think, in fact, that is not correct, if you look at the space station as currently envisioned. It does deal with many of the issues that we have heard raised by the planetary voices here today.

EXPERIMENTAL SCIENCES BENEFITED

Certainly the one area that it is generally conceded, I believe, that the space station will be of tremendous benefit is that of science and space. Peter Banks has touched on that so very eloquently, I won't expand on it too much, but suffice it to say that the experimental sciences—that is, those laboratory sciences of the type that we are used to seeing conducted on the Earth—are fundamentally enabled by the space station with its modules and humans in space.

I would also agree with Peter that we have heard much today attacking the notion of materials processing and commercial return. Candidly,

I have heard none of that from the program over the last 2½ or 3 years since the science community, through Peter's committee and others, has been looking very strenuously at what goes on.

The real theme, the real push is to do the basic research in the life sciences, in the materials sciences, in the fluid sciences, those kinds of research which are fundamentally enabled by the space station as it currently is outlined.

MICROGRAVITY RESEARCH

Certainly as you look, in terms of those kinds of research, one thing that comes up very clearly is that the astute politically powerful astrophysics, planetary, the classic space science community, tends to downplay what might come out of the microgravity research.

It is not my area of research, but I, for one, having looked at the space station for several years, am now convinced that if there is a Nobel prize to come out of space research at all, it will come from the microgravity, the life science type of research, if NASA does its job well in terms of providing that kind of capability. That is a promise that I think we can all look forward to in the beginning of the next century.

CLEARLY ANNOUNCED OBJECTIVES IMPERATIVE

One thing that I think is important—and let me deal with it as it relates to the question of the Mars initiative—I would agree entirely with Carl and Bruce, and other colleagues, who have said that NASA needs a very clearly announced objective, a statement of where it is headed in terms of its future programs. I think that this is something that we desperately need.

It is important to recognize, though, that the current space station does, in fact, allow us to address and deal with some of the very early stages of any major exploration of humans away from the planet Earth.

The issue of the microgravity has come up several times. In fact, if you look carefully at what the life sciences would like to see done in terms of a natural progression of experimental approaches to the problem, and that is what we heard about the animal holding facility, for example, much of this can be done, at least in first order, dealing with smaller specimens than man.

Many of the questions that we need answered, perhaps, can be answered without going to the great expense of building a much larger centrifuge to fly qualified humans in that direct way. If the answer should turn out that it is needed, then, of course, that is an option that we can go to, but the current space station does have the provision to begin the initial stages of research as they are mapped out by the experts in the field; namely, the life scientists themselves.

SPACE STATION SERVICING

The next thing is that the servicing aspects of the space station, which has, in my view, often been strongly overplayed, particularly for astrophysics, has a flip side, and that is the assembly aspects. If one is, in fact, to seriously consider undertaking the Mars mission, we must learn

how to assemble on orbit large-scale facilities, many of these having to do with dangerous propulsive systems of one sort or another.

Although it sounds straightforward, we have, in fact, virtually no experience in this regard. The space station as it is currently envisioned would allow us to begin to gather that valuable experience, both from an engineering and scientific point of view, to address that fundamental piece of a major Mars initiative.

So, although I would agree with my colleagues that the current space station is not specifically ideally designed to match, if we had as our sole objective a Mars mission, it does, in fact, allow us to address the essential first steps in that thrust.

BRIDGING SCIENCE

I would also second the statement from Peter with regard to the preparation as we bridge into the space station era. The space station, I think, as judged by those in the science community who carefully examined what it is and what it is about over the last few years, is, in fact, responsive to the broad range of requirements that the user community has leveled on it.

But if we are to effectively make use of this facility, if and when it arrives, we, the science community in its broadest sense, NASA must match its commitment to the space station with a commitment to do the kind of bridging science that is absolutely essential to be ready to effectively use the space station.

I support the call for extended duration orbiters, and the kinds of things that the task force has looked at over the last several years.

In addition to the facilities that need to be brought forward, NASA must have a commitment to developing the science instruments in a broadly based program, which allows it to take advantage of whatever the space station might provide in these areas.

Mr. Chairman, I think, as we look at the space station, we ask what can it do. We have heard people talk about many things, not many have focused on the space station, in fact. We heard, as I said, much about the frustration of the space science community as it regards the overall policy of the nation in looking toward space.

SPACE STATION AS GATEWAY

The space station is a gateway. It allows us to learn how to live and work in space. As we have seen, many people want to design it for various purposes. In fact, I think, if you look at this particular space station, it has the ability to evolve. As we learn how to do that, as we learn where the next major thrusts are, I believe this space station is responsive to that, and it will allow us to go in those directions.

Thank you for the opportunity to testify today.

Senator PROXMIRE. Thank you, Dr. Black.

Dr. Banks, I think that you make a most dramatic and shocking statement on page 3 of your prepared statement, and I want to read from it, and then ask you about it.

You say:

> The situation, since the *Challenger* accident, has become increasingly catastrophic for our national program of space science. Prior to the accident, a total of 76 equivalent shuttle science payloads were planned between 1986 and 1995. By November 1986, only 22 science payloads remained, and the total number of new U.S. spacelab flights was reduced to just 3.

Then you say:

> It is no exaggeration to say that the science that has been lost is devastating to this nation's program of space research. It cuts across all disciplines and institutions. The message has been echoed by every major advisory committee of NASA, panels of the National Academy of Sciences, and many independent professional organizations. This reduction in the level of effort of the space research strikes at the heart of our ability to continue first rate scientific programs and seriously harms this nation's ability to attract and train scientists and engineers needed in the future.

Then you say:

> Yet, plans for implementing NASA's space station have gone forward independently of any consideration of a total plan of action which might improve the situation for space researchers, and especially for those attempting to use human resources in space.

Unfortunately, we have to cope with a situation in which, although there are some enthusiasts like Senator Garn in the Congress who would like to substantially increase the budget, I think that it is unlikely that we will be able to increase it the way that many would like. As a result, we are going to have to cope with very, very limited resources.

So I would like to discuss with you the concept of developing an inexpensive man-tended space facility as an incremental step toward a permanently manned station.

You say on page 5, in your concluding remarks:

> A low-cost, extended duration orbiter can more than double the science yield of a shuttle flight. This innovation has been in front of NASA for more than a year.

Then you say:

> Second, the use of the industrial space facility now being offered by space industries may provide an interim man-tended capability to help with fundamental microgravity and other studies prior to using space station,

and so forth.

> Third, it is also possible to reschedule one or more of the large platforms included in space station program. This could either accelerate present plans or serve as a stopgap, new capability to serve multiexperiment platforms to ease the current experiment manifest.

It seems that what you are suggesting is that we have an incremental attempt, not to try to go all the way, but some part of the way, and that that might make sense in view of the limited budget. Is that your position?

Mr. BANKS. No; I think that this is in a slightly different context. Let me say that what we are trying to do is ameliorate the difficulty, taking

into account the fact, which may be a very practical fact, that we can't achieve the space station before the middle part of the 1990's. I think that this is a practical fact that fits in with the cost problems that you are talking about.

We simply can't accelerate a space station. We have worked ourselves into a hole with respect to space station for reasons over the past few years. The best we can do is by the middle part of the decade. Unfortunately, there are things that will suffer because of that. Life sciences can't begin until you get people permanently in space.

INTERMEDIATE STEPS PROPOSED

What I am outlining here are intermediate steps that can pick up the gap, steps which are by themselves terribly expensive in the sort of scale of NASA operations, but which give us a leg up, a limp-along capability until the space station becomes available.

Senator PROXMIRE. You are ahead of me, and I am not sure that I do understand this. You are or you are not suggesting that, in view of limited resources, we will have to go a little slower and it will take a little longer. Is that right?

HEAVY LIFT LAUNCH VEHICLE

Mr. BANKS. My presumption is that is what the present space station program is. From my point of view, and I must admit that I am a space enthusiast, let me tell you where I come from. I would come from using a heavy lift launch vehicle and put up a space station in 1992 or 1993.

Senator PROXMIRE. I see, it is the heavy lift launch vehicles that you think is something that we might set up.

Mr. BANKS. I think that if you look to the future Soviet program, I think that if you look at our program, you will discover, in retrospect, that it is the heavy lift launch vehicle which has made many things possible in our program. You will have only to look at the current manifesting of the assembly stage of space station, and its difficulties in accommodating 15 launches of the shuttle, to know that the impact, the positive impact that the heavy lift launch vehicle would have in improving that situation.

Senator GARN. If I could just interject. Dr. Banks is entirely right on that, and I have spent nearly 3 years trying to convince NASA and the Air Force that we need a heavy lift launch vehicle, because you get the shuttle fleet back going, with only four shuttles, and you look at the number of dedicated flights necessary and the time involved in putting up the pieces of the space station with the shuttle, compared to what the heavy lift launch vehicle could do in implementing the space station.

I agree completely, Dr. Banks, we need that heavy lift launch vehicle capability not only for the space station, but there are a lot of other very valid uses for HLLV as well.

Senator PROXMIRE. I have another question, but I will tell you that my problem with the heavy lift launch vehicle is that many of us have the suspicion that it is driven primarily to try to deploy SDI hardware as soon as possible, so that it will become irreversible. Of course, that is a very controversial program.

Mr. BANKS. Could I respond to that?

Senator PROXMIRE. Yes.

Mr. BANKS. In fact, if you look at a capability for going to Mars, and go through the requirements for going to Mars with a manned mission, you will discover that you need between 2½ and 3½ million pounds of orbit, fuels, vehicles, habitation modules. The current space station is about a 500,000 pounds.

The idea of using a heavy lift launch vehicle to implement the space station, and then building on that capability for a series of unmanned flights with rovers and investigative probes, followed by a manned program, makes a great deal of sense. There is a tremendous need for that vehicle in our repertoire of launch vehicles.

Senator GARN. Could I point out one thing on this issue. The supplemental that we are just passing, and I will just quote the last sentence:

> None of these funds may be obligated or expended for any activities associated with accelerating or facilitating any early deployment option for ballistic missile defense.

Whatever people feel about SDI, let's not throw the baby out with the bath water, and kill a heavy lift launch vehicle because you are afraid that it might be used for something you don't like. I think that this has been addressed in the other committee just this morning.

Senator PROXMIRE. We have the language, but I am not sure that it will do the job.

Senator GARN. This President is not going to be around long enough, and probably not even the next one either, to make a deployment decision. It is not a current concern.

NEED FOR COMPREHENSIVE SPACE AGENDA

Senator PROXMIRE. Dr. Murray, I refer to a statement made by T.F. Rogers at the Office of Technology Assessment in a 1983 hearing in the Senate Space Subcommittee. In his statement, Mr. Rogers referred to the need for a comprehensive space agenda, and then added the following:

> Absent agreement upon such a fundamental agenda, it is not clear that we should even begin to obtain such an expensive space infrastructure.
>
> There is little important external demand and no convincing argument that it be obtained in a hurry. The very act of allocating such a large and long-term stream of public dollars in this fashion could well restrict and perhaps even foreclose our ability to provide funds, imagination, administrative leadership to address exceptionally important national space related goals, much less alternative goals, for public investment.

Although that statement was made over 3 years ago, it seems to me that it may be extremely relevant today, and I would like to know whether you agree.

Mr. MURRAY. Yes; I agree, and I have actually published a paper in Science and Technology a year ago, which outlined that problem, the need for the goal, and proposed that the goal be going to Mars on the long term with man. That is how we get the balanced program, because we determine that it is a destination for humans in space, and not just a short-term function.

The expectations of this group, as well as the other, are really very close together, despite the fact that the two gentlemen on my left have spent a lot of their time trying to make the space station happen, and I haven't, they are more knowledgeable of the details,we actually are not very far apart.

I think that what we are differing on is what we think is likely to happen from where we are now. My view of that is that, taking Peter's statement that we ought to have the space station, but we also ought to have a large budget size program or a medium budget size program on top of that that goes in front to do the shuttle extended kind of missions, or other similar things, which is a great idea.

It is the logical next step. Realistically, that is not going to happen. You are either not going to do it, or you are going to delay the whole thing further and aggravate the problem.

The other point of view was that we do the preliminary work on going to Mars. That is true, but we are not going to get the data we need, even if the nominal plan were followed, until the turn of the century, and with any kind of slippage, which is likely, it is going to be later.

All of this rests on the shuttle manifest which nobody believes. There is an inability built into this thing technically and financially. It is built in. So we have to look at these results coming in place later. The space station has slipped 1 year per year since the President of the United States offered it up. To dispose of that, and going to no more slippage is unrealistic. For those reasons, I feel that the thing has to be rethought.

If everything could happen the way it has been advertised, if we could have the precursor program, and we make a decision to go to Mars, and do that quickly, fine, but I don't think that it is going to happen that way. So I really believe that we must face the issue, and in particular finish up by saying, right now, as the negotiations are going on in the Congress, between the House and the Senate, and this whole thing—what is happening on the House side, I think, you are the experts, is that the life sciences are being deemphasized further in favor of higher power levels, so that there are even programmatic tradeoffs being given. So the situation is probably on a track to come out worse than the one that Dr. Black was talking about.

COSTS OF EQUIPPING SPACE STATION

Senator PROXMIRE. Dr. Black, in looking at the way NASA has put together its plans for the space station, I almost think of it as an elaborate house, without any furniture, because NASA hasn't planned on the cost of equipping and using the station. Is that right?

Mr. BLACK. It is beginning to do it, that is correct. In fact, that has been one of the major criticisms and concerns of the committee that I am on, Peter's committee, the task force. We have looked at this over the years, and one of the things that we have been most concerned about, in the budget for the space station, is the facility itself, it is not the equipment that would go into that.

As we both remarked, I think, it is absolutely essential that a commitment by the agency, by the Congress, be made to assure that that funding is available.

Senator PROXMIRE. Can you give us an idea of the cost of that equipment?

Mr. BLACK. It is very difficult to estimate. If you look at the estimates in terms of the equipment, if you take a scaling model with previous spacecraft, manned and unmanned, certainly a number on the order of $3 billion to $5 billion has been talked about over the years, as we become fully operational and use the space station, for the research equipment itself.

Senator PROXMIRE. What about the cost of operation?

Mr. BLACK. If you look at ACSAFF, as an example, which is one of the things that has been talked about, the estimates of that range upward of around $1 billion.

Senator PROXMIRE. One billion dollars a year for operations?

Mr. BLACK. No; that is for ACSAFF as an example.

The operation cost estimates are there, and we have a task force in the programs that has just convened. It has just completed its studies and it is making its presentations. Again, there are estimates there that are on the order of $1 billion a year.

Senator PROXMIRE. Thank you.

Senator Garn.

Senator GARN. Mr. Chairman, time is brief, and you have given me ample time.

MAN-TENDED FACILITY

Mr. BLACK. Senator, may I just add one point to the question that was raised earlier by Senator Proxmire with regard to the man-tended.

As I remarked, the space station is flexible and evolutionary in its whole approach. As you build up, in fact, there is a phase where it is totally man-tended, and that is something that was part of the program initially, as you are perhaps aware. That man-tended aspect is implicit in the evolutionary way in which the structure and the program were put together.

Senator GARN. I was going to say, Mr. Chairman, you were very generous in giving me adequate time to express my opinions and interrupt this panel. With another panel to go, I will refrain from further comments or questions at this point.

Senator PROXMIRE. Thank you, gentlemen. You were, again, a very distinguished panel, and most helpful to this committee.

GENERAL ACCOUNTING OFFICE

STATEMENT OF CARL R. PALMER, ASSOCIATE DIRECTOR, INFORMATION MANAGEMENT AND TECHNOLOGY DIVISION, GENERAL ACCOUNTING OFFICE

ACCOMPANIED BY:
DOUGLAS CANNON, GROUP DIRECTOR
RONALD BEERS, EVALUATOR

Senator PROXMIRE. Our final witness will be Dr. Carl Palmer, who will testify on NASA's planned use of information technology for the space station.

Dr. Palmer, as I understand it, you are from the General Accounting Office. Some people call it bean counting, but I call it good sense. It is good to have somebody who is interested in holding down the cost.

Mr. PALMER. Thank you, sir.

Mr. Chairman and Senator Garn, good morning. We appreciate the opportunity to comment on NASA's plans for developing information technology for the space station. With me today are Douglas Cannon, a group director in the Information Management and Technology Division, who was responsible for this work; and Ronald Beers, the evaluator in charge of our work that was done at the request of the House Committee on Science, Space and Technology.

Senator PROXMIRE. Dr. Palmer, you have an excellent statement here. I suggest that you might summarize the statement. It will be printed in full in the record. Then we can get directly to the questions.

Mr. PALMER. I will be glad to, sir. We have submitted the report to the committee as well.

SYNOPSIS OF STATEMENT

The main point that we have in our report is that we have identified several issues that relate to the development of information technology for the station that we believe that NASA and the Congress may want to consider in their deliberations on the space station program.

The report, which we will be glad to submit for the record, also addresses some issues with respect to both the unmanned or the space science area, as well as the shuttle portion.

The major issue, as we see it, facing NASA is the need to make a substantial early investment in order to develop extensive advanced information technology to run the station efficiently and effectively over its life versus the need to hold down the initial development costs.

The second major issue relates to the schedule that NASA is pursuing to design and build the station's physical structure as compared to its slower pace of developing information technology, particularly automation.

Concerns expressed by the scientific community and NASA representatives lead us to raise questions about the development of the information technology for the space station and the effect that this development could have on the station's operating costs and capabilities.

DEVELOPMENT OF INFORMATION TECHNOLOGY

The significant points that we have are addressed within the testimony. The main one is that there is a limited amount and priority in addressing information technology. It is very minimal compared to what was called for, for instance, by the advisory committee, or by the Congress, in terms of the 10 percent goal of public law.

To summarize our main point, if you will, which is contained on the last two pages of our prepared testimony, NASA will soon be making the important tradeoff decisions that could significantly affect the costs and operational capabilities of the station possibly for its estimated life span of 30 years. In light of the large investment that the agency is planning, there are several key questions that we believe NASA and the Congress may want to consider, including:

KEY QUESTIONS TO CONSIDER

First, if NASA remains committed to its cost and time frame goals for designing and developing the station, will it have to use a minimal risk approach, which would involve, in large part, the use of existing technologies for most station systems?

Second, if a minimal risk approach is taken, will this force NASA to rely primarily on proven, existing information technology that may be seriously outdated by the time the station is placed in operation?

Third, will NASA be incurring the risk of building a less effective station with excessive operating costs and extensive dependence on ground stations for its long life?

Given NASA's revised plans for a phased deployment program, the importance of the agency's development of information technology for the space station takes on added significance and warrants close attention.

NASA may now have a window of opportunity that could allow it to bring more advanced information technology into the final design process for the station. This could lead to a more economic operation of the station over its proposed life and permit incorporation of automation or robotics capabilities for more autonomous operations and reduced dependency on ground support.

Thank you, sir. I will be glad to try to respond to your questions.

[The statement and report follow:]

STATEMENT OF DR. CARL R. PALMER, ASSOCIATE DIRECTOR, INFORMATION MANAGEMENT AND TECHNOLOGY DIVISION, GENERAL ACCOUNTING OFFICE

Mr. Chairman and Members of the Subcommittee:

We appreciate the opportunity to comment on the National Aeronautics and Space Administration's (NASA's) plans for developing information technology for the Space Station. At the request of the House Committee on Science, Space, and Technology, we recently issued an interim report[1] on this subject and other space programs. In our report we have identified several issues related to the development of information technology for the station that we believe NASA and the Congress might want to consider.

The Space Station is one of the most challenging projects that NASA has ever undertaken. The agency is pursuing an aggressive plan to build the station, with "man-tended" capabilities now planned for 1995. A major issue facing NASA is the need to make a substantial early investment in order to develop extensive advanced information technology to run the station efficiently and effectively over its life versus the need to hold down initial development costs. A second issue relates to the schedule that NASA is pursuing to design and build the station's physical structure as compared to its slow pace of developing information technology, particularly automation. Concerns expressed by the scientific community and NASA representatives lead us to raise questions about the development of information technology for the Space Station and the effect that this development could have on the station's operating costs and capabilities.

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[1] Space Operations: NASA's Use of Information Technology, GAO/IMTEC-87-20, April 17, 1987.

NASA's use of information technology is significant, accounting for about 10 per cent of the agency's $7.8 billion fiscal year 1986 budget. From 1987 through 1991, NASA plans to spend about $4.1 billion on new information technology projects, with about $177 million, or 4.3 percent, supporting the Space Station. NASA has developed, and the Congress is now considering, changes to the Space Station program. These include revised cost estimates, a phased deployment of capabilities (for example, the delay in deploying the U.S. coorbiting platform and the servicing facility), and an extended timeframe for the detailed design, development, and operation of the station. Once these cost and timing issues are resolved, the adequacy of NASA's plans for developing Space Station information technology may take on even greater importance than before, especially if previously planned initial capabilities are delayed and NASA decides to allocate most of the available funding to the station's physical design and development.

PROGRAMS TO DEVELOP INFORMATION TECHNOLOGY FOR THE STATION

NASA documents and studies by the scientific community show that the successful development of information technology for the station, including the use of advanced automation and robotics,[2] and high-quality software will play key roles in achieving specific objectives and program effectiveness and in controlling life-cycle costs.

Advanced automation, if developed and implemented properly, can improve both ground and on-orbit operations. It can also increase computer systems' abilities to support innovation, allow the Space Station to operate autonomously, lower operating costs,

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[2]Advanced automation and robotics can be defined as the use of machines, either computers or robots or both, to perform predesignated tasks largely without human intervention.

and increase crew productivity. For example, on the basis of the Skylab and Shuttle experiences, individual crew members have about 10 productive hours per mission day. Of this, approximately 4 hours per day or 40 percent of productive time are used to verify and calibrate on-board instrument readings. NASA studies show that these activities could, in large part, be accomplished by automation.

The use of robotics may reduce risks to humans in performing hazardous tasks associated with space flight. Additionally, the use of high-quality software is important to controlling software maintenance costs and will facilitate the eventual transfer of ground-based functions to the station.

NASA's Automation and Robotics Technology Development Program, the Space Station Information System, and the Technical and Management Information System are three key programs currently under way to develop and implement advanced automation and high-quality software for the station. The automation technology program focuses on development of the technology base for advanced automation and robotics, while the Space Station Information System and Technical and Management Information System projects deal mostly with system design and implementation, including the design of high-quality software.

CONCERNS ABOUT AUTOMATION AND SOFTWARE

Concerns have been expressed by the scientific community and NASA representatives that the agency's automation plans and advanced information technology development efforts were not progressing as quickly as the efforts to design and build the station. As a result, the station's initial capabilities may include only limited advanced automation, making initial operations expensive and inefficient. Further, studies we reviewed showed

that if NASA does not design the station so that it can incorporate advanced automation over time, subsequent rebuilding of information systems to include more automated designs could be extremely costly.

One organization that has expressed concern about the development of automation and robotics for the station is the Advanced Technology Advisory Committee. This committee was created by law[3] to identify specific Space Station systems that advance the state-of-the-art in automation and are not in use in existing spacecraft. The committee noted in its first report issued in 1985[4] that, although the station would not initially have significant on-board automation, it was critical that the station's design be flexible enough to accommodate future automation enhancements. The advisory committee reported, however, that much complex research and development of several key advanced technologies had to be addressed long before they could be used for either the station's initial or later configurations.

A recent advisory committee progress report[5] stated that, although NASA's planned use of robotics was promising, planning for some kinds of advanced automation technology was not progressing quickly enough to significantly influence station design. To underscore its concern, the committee noted that the results of the automation work to date had not been incorporated into design control documents that NASA would include in the requests for proposals for the detailed design and development contracts for the

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[3]Public Law 98-371 (98 Stat. 1227), July 18, 1984.

[4]Advancing Automation and Robotics Technology for the Space Station and for the U.S. Economy, NASA-TM87566, March 1985.

[5]Advancing Automation and Robotics Technology for the Space Station and for the U.S. Economy-Progress Report 3, NASA-TM89190, October 1986.

station. The advisory committee believed that the primary inhibitor of automation planning for the station was NASA's constraint to design the station to an initial target cost, without giving balanced consideration to operational (life-cycle) costs.

The advisory committee recommended that NASA (1) set aside funds for advanced automation or (2) consider both the estimated life-cycle costs and the initial development costs when evaluating the proposals submitted by contractors competing for the station's detailed design and development contracts. Without NASA's commitment to one of these alternatives, the committee reported that it expected to see limited advanced automation on the initial station; an excessively costly process to incorporate evolutionary growth in advanced automation; a station that would be expensive to operate with a large dependence on ground stations; and a station that could not support autonomous operations.

In responding to these concerns, NASA stated that it would ensure that the final requests for proposals for the detailed design and development contracts addressed the importance of automation and robotics. The four draft requests for proposals issued by NASA for the detailed design and development contracts tend to support the advisory committee's basis for concern about the design control documents. Specifically, two key automation requirements documents that had been developed earlier in the Space Station's program were not properly updated or, in three of the four proposals, were not included as documents that would be binding on the contractors who will do the detailed design of the Space Station's information system architecture. These design control documents are important because they addressed requirements

for the growth and incorporation of expert systems[6] in the Space Station. At the time we prepared our April 17 report, NASA had not issued the final proposal requests. We recently learned that these requests were issued on April 24; however, we have not yet been able to determine if NASA has changed the requests to incorporate the advisory committee's recommendations.

The advisory committee has not been alone in expressing concerns about information technology for the station. For example, a 1985 Office of Technology Assessment study[7] conducted for the Congress expressed concern that, unless NASA funds automation research and development at levels substantially greater than currently projected levels, the Space Station would not include significant automation and its eventual evolution beyond initial capabilities would be hampered. More recently, NASA officials expressed concerns to us that the tools and procedures that will guide contractors in developing high-quality software for the station may not be ready when needed.

NASA has taken some action to address these concerns, including appointing a Division Director in the Office of Space Station with direct responsibility for automation and robotics. In 1985 the agency intensified its program for research and development of the use of automation and robotics technology. Funding for this program has increased from $4.9 million in fiscal year 1985 to $18.2 million in fiscal year 1987, with $25.4 million requested for 1988. This amount is, however, about $55 million less than the fiscal year 1988 level recommended by the Automation

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[6]An expert system is a computer program that performs at the level of a human expert in solving specific problems.

[7]Automation and Robotics for the Space Station: Phase B Considerations, An OTA Staff Paper, 1985.

and Robotics Panel,[8] to provide a minimally effective automation and robotics technology program for the station.

NASA will soon be making important trade-off decisions that could significantly affect the cost and operational capabilities of the station, possibly for its estimated life span of 30 years. In light of the large investment that the agency is planning, there are several key questions that we believe NASA and the Congress might want to consider, including:

-- If NASA remains committed to its cost and timeframe goals for designing and developing the station, will it have to use a "minimal risk approach," which would involve, in large part, the use of existing technologies for most station systems?

-- If a minimal risk approach is taken, will this force NASA to rely primarily on proven, existing information technology that may be seriously outdated by the time the station is placed in operation?

-- Will NASA be incurring the risk of building a less effective station with excessive operating costs and extensive dependence on ground stations for its long life?

Given NASA's revised plans for a phased deployment program, the importance of the agency's development of information technology for the Space Station takes on added significance and warrants close attention. NASA may now have a "window of opportunity" that could allow it to bring more advanced information technology into the final design process for the station. This

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[8]Automation and Robotics for the National Space Program, Automation and Robotics Panel, Administered by the University of California, California Space Institute, Report CSI/85-01, February 25, 1985.

could lead to a more economic operation of the station over its proposed life and permit incorporation of automation and robotics capabilities for more autonomous operations and reduced dependency on ground support.

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That concludes my testimony Mr. Chairman. I will be happy to answer any questions you or Members of the Subcommittee may have at this time.

REPORT

UNITED STATES GENERAL ACCOUNTING OFFICE

SPACE OPERATIONS: NASA'S USE OF INFORMATION TECHNOLOGY

United States
General Accounting Office
Washington, D.C. 20548

Information Management and
Technology Division

B-226577

April 17, 1987

The Honorable Robert A. Roe
Chairman, Committee on Science, Space, and Technology
House of Representatives

Dear Mr. Chairman:

In response to a July 1, 1986, request from the former Chairman (see appendix I), we are providing an overview of the information technology[1] that is critical to the missions of the National Aeronautics and Space Administration (NASA). As requested, this report discusses NASA's planning, development, and use of information technology for three areas: the Space Transportation System (STS), the Space Station, and unmanned space explorations. (For details, see appendixes II-IV, respectively.)

NASA's use of information technology is significant. In fiscal year 1986, NASA allocated about $784 million for this technology, about 10 per cent of the agency's total $7.8 billion budget. During fiscal years 1987 through 1991, NASA plans to spend about $4.1 billion on new information technology projects, approximately 70 percent of which will support STS, Space Station, and unmanned space programs. (Appendix V contains additional information on NASA's planned acquisitions.)

In performing our review, we examined pertinent management, technical, and contract information provided by NASA. We also held discussions with NASA representatives responsible for the direction of the information technology support for the agency's space programs. We conducted our work at NASA headquarters in Washington, D.C., and at selected NASA field locations, including Goddard Space Flight Center, Jet Propulsion Laboratory, Lyndon B. Johnson Space Center, John F. Kennedy Space Center, and the White Sands Test Facility. Where possible, we have updated the information in this report through February 1, 1987. Details on our scope and methodology can be found in appendix VI.

Footnotes at end of report.

Additional work is necessary before we can reach final conclusions, or make recommendations, on the topics discussed in this report. However, as requested during progress briefings with your office, we have identified several issues related to STS, the Space Station, and unmanned space explorations that the Committee may wish to pursue.

SPACE TRANSPORTATION SYSTEM

STS information systems architecture, both the hardware and software that support the system's operations, merits close attention, as the space program continues to recover from the loss of the Challenger in 1986. According to NASA officials, the existing architecture is obsolescing, thus possibly limiting flight rates and potentially becoming an even larger obstacle to operational efficiency as NASA attempts to perform more complex missions in the future. NASA has several modernization projects under way, but additional work is needed to determine if these projects fully address the obsolescence problem.

STS' overall operational performance depends not only on the number of shuttle orbiters and the time it takes to refurbish them between flights, but also on the efficiency and effectiveness of three key mission operations: flight planning, flight readiness, and flight control. According to NASA officials, much of the STS software and hardware used to support these operations was originally designed for the 1960s Gemini and Apollo projects, whose missions were operationally different from those of STS. These officials have also said they recognize that the existing hardware and software architecture that supports current operations may be nearing the end of its useful life, has limited spare equipment, and requires extensive time to modify from flight to flight. A 1986 NASA flight rate capability study[2] points out that, depending upon the mission complexity, existing flight planning and software development and production operations may not be able to support the flight rates that NASA currently plans. As STS mission tasks become more complex (for example, constructing, assembling, and servicing the Space Station), architectural obsolescence could become an obstacle to efficient and effective operations. As a result, according to NASA officials, operations costs could rise, or the number and type of missions that could be flown could be limited, or both.

NASA has several projects to update selected automated data processing systems supporting mission operations. In addition, NASA's Johnson Space Center has projects that are exploring the use of advanced automation to improve the effectiveness and efficiency of certain flight control operations. However, the obsolescence issue may need further attention. To illustrate, although NASA has progressed in developing a long-range architecture plan for financial and administrative information systems, the agency has not developed an integrated long-range plan for flight planning, readiness, and control systems that identifies (1) current performance shortfalls, including

obsolescence issues, and (2) modernization plans for addressing these issues.

In January 1987, NASA announced that it was taking steps to place greater emphasis on long-range operational planning and system design for STS operations overall. In view of this, NASA and the Committee may wish to address several key questions, including:

-- To what extent, and at what cost, can the existing STS hardware and software support the number and complexity of missions currently planned?

-- To what degree can existing hardware and software support an effective and efficient assembly and servicing of a space station? and

-- What opportunities exist for using advanced automation and information technologies to improve STS' operations, and what is NASA's plan to incorporate these new technologies?

SPACE STATION

According to NASA representatives, the Space Station is one of the most challenging projects that the agency has ever undertaken. The agency intends to move rapidly toward awarding contracts for the detailed design and development phases. At the same time, it hopes to contain initial development costs. Successful development of the station will require NASA to solve many critical issues over the life of the Space Station project. According to NASA officials, determining the level of advanced automation that will be needed to run the station efficiently and effectively, while containing development costs, represents a major issue. NASA documents indicate that acquiring the benefits of advanced automation will require complex research and development in information technology.

During this review, we noted concerns by the scientific community and NASA representatives that the agency's automation plans and advanced information technology efforts are not progressing as quickly as the agency's efforts to design and build the Space Station. As a result, the station may include only limited advanced automation, making initial operations expensive. Further, studies show that if NASA does not design the station so that it can incorporate advanced automation over time, subsequent redesign of the station could be extremely costly.

One organization that has voiced concern about the Space Station is the Advanced Technology Advisory Committee. This committee was created by law[3] to identify and recommend Space Station systems that should use advanced automation and robotics[4] technology. The advisory committee noted in a 1985 report[5] that, although the station would not initially have significant on-board automation, it was critical that the station's design be flexible enough to accommodate future automation enhancements. The advisory committee explained, however,

that much complex research and development of several advanced information and communication technologies had to be addressed long before they could be used for either the station's initial or later configurations. A recent advisory committee report[6] stated that, although NASA's planned use of robotics looked promising, planning for some kinds of advanced automation technology was not progressing quickly enough to significantly influence station design. To underscore its concern, the committee noted that the results of the automation work to date had not been incorporated into the design control documents, which were to be used for the detailed design and development contracts. The advisory committee believed that NASA's constraint to design the station to an initial target cost, without giving balanced consideration to operational or life-cycle costs, was the primary inhibitor of automation planning for the station.

On the basis of its concerns, the advisory committee recommended that NASA (1) set aside funds for advanced automation or (2) consider both the estimated operational (life-cycle) costs and the initial development costs when evaluating the proposals submitted by contractors competing for the station's detailed design and development contracts. Without NASA's commitment to one of these alternatives, the committee reported that it expected to see limited advanced automation on the initial station; an excessively costly process to incorporate evolutionary growth in advanced automation; a station that would be operationally expensive; and a station that could not support autonomous operations.

In responding to these concerns, NASA has stated that it will ensure that the final requests for proposals for the detailed design and development contracts will address the importance of automation and robotics. To give automation and robotics a more significant role in station design, the agency said that it had appointed a Division Director in the Office of Space Station with direct responsibility for this area.

Our preliminary review of the four draft requests for proposals issued by NASA for the detailed design and development contracts supports the advisory committee's basis for concern about the design control documents. For example, two key automation requirements documents developed to date were not properly updated or, except for one instance, were not included as documents that would be binding on the contractors who will do the detailed design of the Space Station's information system architecture. At the time we prepared this report, NASA had delayed issuing the final proposal requests. Thus, we could not determine whether NASA had changed the requests to incorporate the advisory committee's recommendations.

We also noted other concerns about information technology for the station. For example, the report from a 1980 NASA

sponsored study[7] pointed out that, unlike its pioneering work in other areas of science and technology, the agency's use of computer science and machine intelligence for advanced automation had been conservative and unimaginative and was 5 to 15 years behind the leading edge of technology. Also, NASA officials have expressed concern that tools and procedures that will guide contractors in developing high-quality software for the station may not be ready when needed. Finally, a 1985 Office of Technology Assessment study[8] conducted for the Congress expressed concern that, unless NASA funds automation research and development at levels substantially greater than currently projected levels, the Space Station would not include significant automation and its eventual evolution beyond initial capabilities would be hampered.

NASA has taken some action to address these concerns, including intensifying, in 1985, its program for research and development of the use of automation and robotics technology. Funding for this program has increased from fiscal years 1985 through 1987, with additional funding requested for 1988.

NASA may soon be making important tradeoff decisions that could significantly affect the cost and operational capabilities of the station, possibly for its estimated life span of 30 years. In light of the large investment that the Space Station will likely require, NASA and the Committee may wish to consider addressing several key questions, including:

-- If NASA remains committed to its cost and timeframe goals for designing and developing the station, will it have to use a "minimal risk approach," which would involve, in large part, the use of existing technologies for most station systems?

-- If a minimal risk approach is taken, will this force NASA to rely primarily on proven, existing information technology that may be seriously outdated by the time the station is placed in operation?

-- Will NASA be incurring the risk of building a less effective station with excessive operating costs and extensive dependence on ground stations for its long life?

UNMANNED SPACE EXPLORATION

In addition to its manned space missions, NASA has a goal of extending scientific knowledge about space through unmanned exploratory missions to survey Earth, the rest of our solar system, and the universe. Information technology is used to support three major areas of unmanned space exploration: telecommunications, space science data management, and spaceflight control operations. NASA has ongoing programs to improve

operations in these areas. However, we noted concerns by the scientific community and NASA representatives about the capacity of telecommunications systems to meet planned future needs; NASA's processing, distribution, and archiving of science data; and the efficiency of spaceflight control operations.

In telecommunications, NASA initially planned to rely on a space network of three satellites (two active and one spare) to relay data between all low Earth orbiting spacecraft and ground stations through the early 1990s. One satellite is currently in orbit, and two more are planned to be launched when the shuttle resumes flights. NASA documents indicated that the two active satellites may not be adequate to handle the substantial telecommunications needs of STS, the Space Station, and all other low Earth orbiting spacecraft. This could result in significant losses of scientific data. Furthermore, the agency's networks for transferring data among different NASA locations may not be able to handle the increasing demands being placed on them and could add to the potential telecommunications shortfall.

NASA officials told us that the agency will continue to assess the requirements for the space network and update its plans, if necessary, to launch two additional satellites to support the Space Station. However, our review of the payloads for all planned shuttle flights through 1994 did not show launches for the two additional satellites.

Concerning space science data management, NASA has been criticized in the past by the scientific community for its performance in processing, distributing, and archiving space science data. Although NASA is attempting to respond to some of these concerns by funding "pilot" data management systems and acquiring additional computing resources, the agency's efforts may not go far enough. Scientists now expect space data to be generated at a far greater rate by the end of the decade than has ever been produced in the past. For example, NASA program managers for the planned earth observing system estimate that the system will have to receive, process, and store 10 trillion bits of data per day. To illustrate the magnitude of this number, if the data were stored on standard magnetic tape (6,250 bits of data per inch of tape), there would be enough tape to encircle the earth each day. While no one, to our knowledge, has proposed using magnetic tape to store this data, considerable advances must still be made to accommodate the projected massive storage needs.

Regarding spaceflight control operations, NASA's Solar System Exploration Committee, Subcommittee on Mission Operations and Information Systems, has expressed concerns about the duplication of effort in establishing multiple mission control centers for unmanned satellites and probes instead of consolidating these efforts. In an effort to partially address this concern, the Jet Propulsion Laboratory is planning to establish a consolidated deep

space flight operations center. However, we have not yet seen evidence that NASA has identified what technical risks would be involved in the consolidation project.

Considering the significant financial and human investments that are being made by NASA and the scientific community in the unmanned space area, NASA and the Committee on Science, Space, and Technology may wish to consider addressing several key questions, including:

-- What specific action is NASA taking to ensure that its space and ground-based telecommunications systems will be able to handle the massive amounts of scientific data that it anticipates processing in the near future?

-- What plans does NASA have to ensure that its ground facilities will be able to adequately communicate, process, distribute, and archive such volumes of data from satellites and other systems, like the planned Earth Observing System, in a high quality manner?

-- Although NASA is taking steps to make space flight operations control more efficient by establishing the space flight operations center, what other alternatives are available in conjunction with the center? For example, is there potential for using advanced automation in on-board satellite systems to alleviate some of the burden of managing routine functions that are now controlled from the ground? Also, how would the use of advanced automation, along with more efficient ground operations, reduce overall life-cycle costs?

AGENCY COMMENTS AND OUR EVALUATION

NASA stated that, in large part, our report presented a correct picture of the agency's use of automated information technology in support of space operations. Nevertheless, NASA believed there were several areas that were not properly addressed in the report. Specifically, the agency stated that our report did not adequately address the current and planned ground support systems used to support NASA missions. NASA also stated that we had made an incorrect assumption about the final space network configuration for the Space Station era. Finally, regarding the Advanced Technology Advisory Committee's concerns about the use of automation and robotics for the Space Station, NASA provided us with additional information that it believed accurately represented the agency's views regarding the Committee's report and resulting actions that NASA has planned or has taken.

Regarding our description of ground support systems, our report is intended to be an overview of information technology critical to NASA's space missions. It is not intended to be a comprehensive survey of all space-related information technology projects being pursued by the agency. We note on numerous pages in the report that NASA

has modernization projects under way in several information technology areas, including ground support systems. We did not believe it was appropriate for this overview to include detailed descriptions of every information technology project. However, we did consider all projects mentioned by NASA in its comments on the draft report in our review.

Concerning the space network configuration, the information in our draft report was accurate, based on the information we reviewed. For example, both NASA documents and officials indicated that the space network configuration considered for the early to mid-1990s included two active and one spare telecommunications satellites. NASA's manifest for shuttle flights planned from the time flights resume through 1994 verified this configuration. Specifically, the manifest did not show plans to launch the two additional satellites that the agency included in its 1986 long-range plan. We made several additions and technical corrections in appendix IV to better reflect NASA's long-term plans for the space network. However, we believe the issue regarding the agency's plans for space and ground telecommunications systems is still valid for discussion because of other constraints raised by NASA's long-term plans.

Finally, the information that NASA provided us regarding the Advanced Technology Advisory Committee concerns was considered in preparing our draft report.[9] We included several references in appendix III about the agency's planned or ongoing actions to address the committee's concerns.

NASA also raised several technical and editorial points about our draft report, which we have addressed. The agency's points and our comments are included in appendix VII.

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As arranged with your office, unless you release its contents earlier, we plan no further distribution of this report until 30 days from its issue date. We will then send copies to interested parties and make copies available to others upon request. Should you need additional information or have any questions on the contents of this document, please contact Dr. Carl R. Palmer, Associate Director, on 275-4649.

Sincerely yours,

Ralph V. Carlone
Director

APPENDIX I

Request Letter

DON FUQUA, Florida, CHAIRMAN

ROBERT A. ROE, New Jersey
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U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY
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JOE BARTON, Texas
D. FRENCH SLAUGHTER, JR., Virginia
DAVID S. MONSON, Utah

HAROLD P. HANSON
Executive Director
ROBERT C. KETCHAM
General Counsel
JOYCE GROSS PREWALD
Republican Staff Director

July 1, 1986

Hon. Charles A. Bowsher
Comptroller General
U.S. General Accounting Office
Washington, DC 20548

Dear Mr. Bowsher:

The Committee on Science and Technology intends to continue to broaden its oversight of NASA's information technology and automation activities critical to its space missions. NASA has long been heavily dependent on information technology for its space mission effectiveness. Indeed, NASA is the largest federal user of information technology for civilian purposes. Highly complex, information and automation technology is at the heart of all of NASA's space missions--from unmanned space exploration to Shuttle operations to its proposed space station. Further, NASA's investment in increasingly complex information and automation technology is growing. As a result of all this, NASA faces tremendous challenges in effectively developing and applying the technologies necessary for all its programs and especially for the Space Station program.

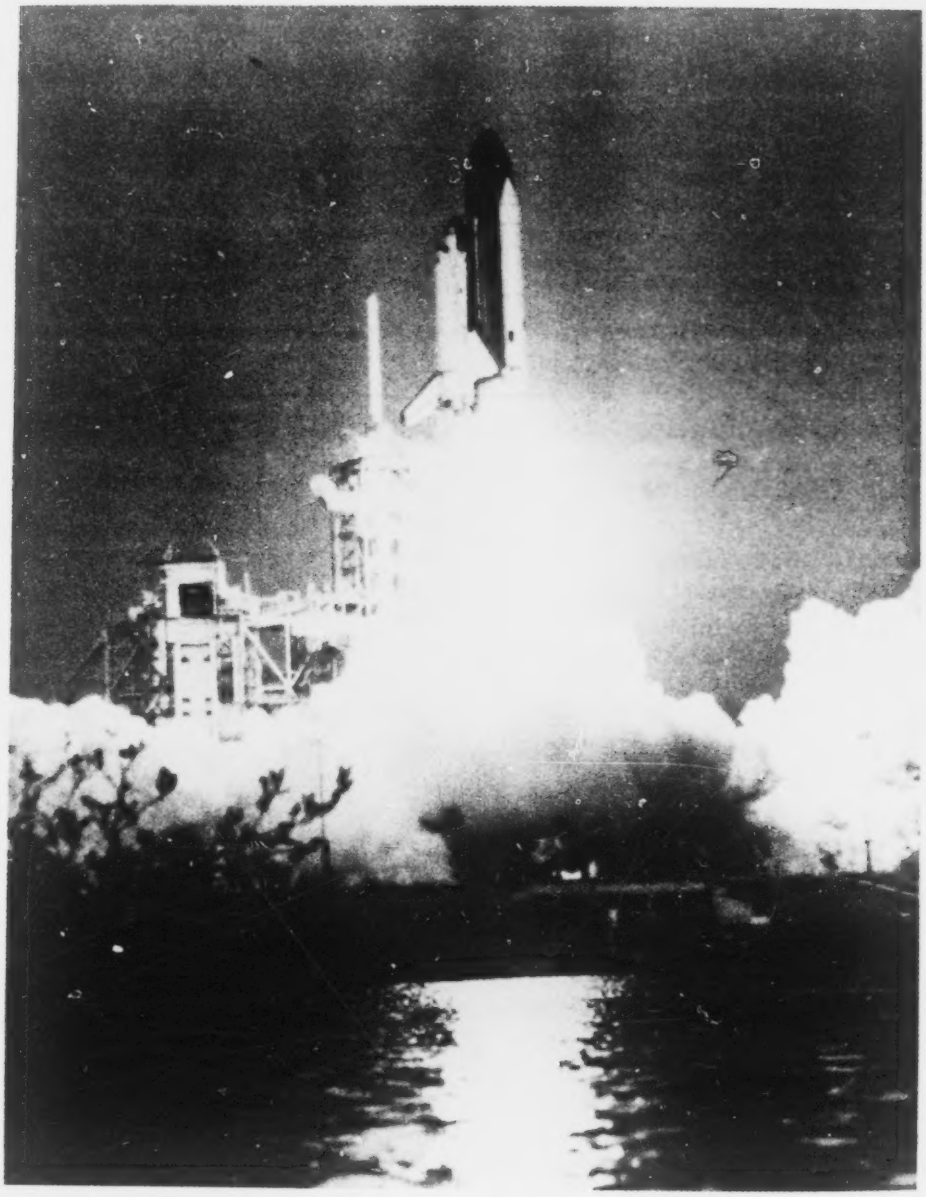
The Committee is interested initially in information in three areas: NASA's planning and development of ADP and automation technology for the Space Station, especially expert systems and automation technology useful to reduce operations costs; NASA's modernization of information technology for the Shuttle program; and NASA's information technology for unmanned space exploration. The Committee would like a summary overview on the above areas by January 1987. Recognizing this short timeframe, the overview should focus on providing information that will give the Committee a general understanding of NASA's information technology and automation investment for the above areas. If you have any questions, please contact Dr. Radford Byerly (225-7858) of the Committee staff.

Sincerely,

DON FUQUA
Chairman

DF/Bvt

APPENDIX II



Source: NASA

ABBREVIATIONS

ATAC	Advanced Technology Advisory Committee
CODMAC	Committee on Data Management and Computation
GAO	General Accounting Office
JPL	Jet Propulsion Laboratory
NASA	National Aeronautics and Space Administration
OTA	Office of Technology Assessment
STS	Space Transportation System

SPACE TRANSPORTATION SYSTEM

The overall performance of NASA's Space Transportation System depends not only on the number of shuttle orbiters and the time it takes to refurbish them between flights, but also on the efficiency and effectiveness of key mission operations. The effectiveness and efficiency of these operations, in turn, are dependent on how well supporting hardware and software systems work. According to NASA officials, the existing overall architecture of these hardware and software systems is obsolescing and may limit the effectiveness and efficiency of mission operations.

As the STS program continues to recover from the loss of the space shuttle Challenger in January 1986, architectural obsolescence could become quite significant, particularly as STS mission tasks become more complex (for example, the planned assembly and servicing of a space station). Although NASA has several modernization projects under way, additional work is needed to determine if these efforts fully address the obsolescence issue.

STS: AN OVERVIEW

NASA developed STS to reduce the cost of space operations and provide easy access to space for commercial enterprises, foreign governments, the Department of Defense, and other government agencies. In addition to the shuttle orbiter, external fuel tank, and solid rocket boosters, STS includes computer hardware and software that support key mission operations, such as flight planning, flight readiness, and flight control. Table II.1 lists the large, complex hardware and software, which are manufactured by several companies, that currently support these operations and the major information systems/facilities that use the hardware and software. The software needed to support STS mission operations consists of approximately 25 million lines of software code and is written in at least six languages.

Overall management of the STS is the responsibility of NASA's Office of Space Flight. The STS planned budget for fiscal year 1987 is about $4.95 billion, of which $2.1 billion is appropriated for a new orbiter. Of the remaining $2.85 billion, NASA spends approximately $840 million annually for mission operations. A description of these operations follows.

Table II.1: Hardware and Software Supporting Mission Operations

MI SION OPERATIONS	HARDWARE USED	SOFTWARE/LANGUAGES USED
Flight Planning		
--Flight Design Systems	--Unisys 1100s --Perkin Elmer 32/42 --Hewlett Packard 9000s	--4.7 million lines of code --Fortran 66, Fortran 77
--Crew Activity Planning System	--DEC/Vax 11/750s and VS100s	--57,000 lines of code --Fortran 77
--Remote Manipulator Planning System	--Hewlett Packard 9000s	--22,000 lines of code --Fortran 77 --Fortran V
Flight Readiness		
--Software Development	--Amdahl 5870 and 800 user terminals	--1.3 million lines of code --PL1, HAL 360, ADF, and assembly code
--Software Production	--IBM 3033s --IBM 3084 --AT&T 6300 PC Terminals --IBM SPF Terminals	--2.3 million lines of code --PL1, Unix and C
--Mission Simulation	--Unisys 1100s --IBM AP101s --Perkin Elmer 832s and 352s	--1.6 million lines of code --Fortran V --Assembly code
Flight Control		
--Launch Processing	--ModComp II/45s --Honeywell 66/80s --Honeywell DPS 8/70s	--13 million lines of code GOAL (custom language)
--Mission Control	--IBM 3083s --IBM 3081	--1.8 million lines of code --Fortran IV --PL1 --Assembly code
On-board		
-- uttle on-board	--IBM AP101s	--Over 580,000 lines of code HAL (custom language) --assembly code

Flight planning operations and systems

Flight planning operations produce the trajectories and schedules for crew and mission activities that are feasible, consistent, and satisfy mission operational requirements. Flight planning systems include the flight design system, the crew activity planning system, and a planning system for the remote manipulator system.

The flight design system is used to analyze and design each mission's flight plan, including ascent/descent analysis and design, on-orbit flight design, attitude and pointing (that is, orbiter position) planning, and analysis of the effects of the orbiter's flight path on such consumable items as fuel, water, oxygen, and batteries.

The crew activity planning system develops, analyzes, and schedules all activities that the orbiter crew will perform in flight, including routine activities, such as eating and sleeping, as well as the more complex non-routine activities, such as maneuvering or deploying payloads. The system also produces a plan that the crew takes on board.

The planning system for the remote manipulator system is used to plan and evaluate the operation of the orbiter's remote manipulator, a 50-foot-long mechanical arm mounted in the orbiter's cargo bay, which is used in such space operations as satellite retrieval.

Flight readiness operations and systems

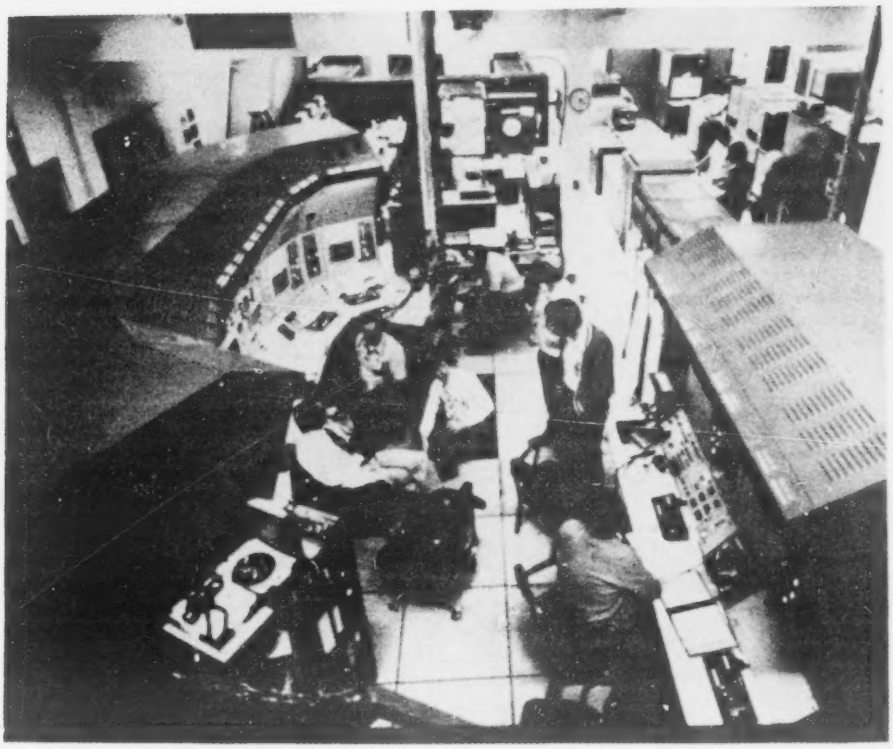
Flight readiness operations produce the software necessary for each flight, support the training for each flight through simulation, and modify the mission control system for each flight. Flight readiness systems consist of the software development system, the software production system, and the mission simulation system.

According to a NASA official, the software development system modifies and adds new computer logic and equations to enhance shuttle operational capabilities. For example, the system is implementing a recently recommended change to improve shuttle safety by including an additional abort capability.

The software production system complements the software development system by modifying the vehicle, payload, and avionics data that are unique for each mission and by producing an overall software package for each flight. Specifically, the system collects and integrates the type of actual flight data, from both the shuttle and its payloads, that is to be monitored and the process for doing so. The system then uses this requirements data to produce a tape that will format telemetry data and integrate it with other shuttle data to produce a complete flight software package for the on-board computers. According to a NASA official, the software production system also produces software products that modify the mission control computers that will process and route the telemetry data and modify the workstations that display selected telemetry data to specific flight personnel.

The mission simulation system trains flight and ground crew members in handling both normal and contingency operations they may face in each flight stage: prelaunch, ascent, on-orbit (for example, payload deployment), descent, landing, and abort. The system conducts integrated simulations in conjunction with the mission control system. These simulations are a complete rehearsal of an actual shuttle mission, including the exchange of data and voice communications between the shuttle mission simulator and the mission control center. Figure II.1 shows an operator station for the shuttle mission simulator. Thousands of simulated flight conditions can be set or reset from these stations.

Figure II.1: Shuttle mission simulator control center



Source: NASA

Flight control operations

Flight control, from prelaunch to orbit to landing, centers around the launch processing system, the mission control system, and the shuttle on-board system. The launch processing system at the Kennedy Space Center performs pre-flight checkout and monitoring of the space shuttle vehicle and controls its launch. This includes monitoring critical measurement data and displaying it in "real-time"[10] to different operator consoles in the launch control center at Kennedy, which, in turn, can relay commands directly back to the shuttle vehicle. Overall, about 40,000 temperatures, pressures, flow rates, turbine speeds, voltages, switch positions, and other parameters are monitored several times per second.

The Johnson Space Center uses the mission control system to perform real-time command and control of shuttle flights from launch through landing, to flight crew egress. Once the shuttle clears the launch tower at Kennedy, control of the mission switches instantly from launch control at Kennedy to mission control at Johnson. The mission control system also supports preflight and non-flight activities, such as flight simulations, launch pad tests, communications network tests, and software testing and validation. (Figure II.2 shows a mission controller console for the mission control system at Johnson.)

In its real-time mode, the system processes command, trajectory, communication and telemetry data; displays the data to flight controllers; processes and transmits controller commands to the orbiter; and displays the responses received from the orbiter. A digital television subsystem displays to the flight controllers

Figure II.2: Controller console for mission control system at Johnson Space Center

Source: NASA

the data computed on board the shuttle, as seen by the crew. In analyzing potential failure conditions, flight controllers will often use some of the 250 analysis programs that are kept on off-line computers due to loading limitations on the mission control system. The screens in front of each operator display thousands of different measurements that must be monitored constantly during a flight.

The on-board computers are involved in the control and monitoring of almost every phase of shuttle operations, from vehicle testing at the orbiter manufacturer's plant through ascent, orbit, re-entry, and landing. A set of five of these computers constitutes the orbiter's avionics (that is, aeronautic and electronic systems). Four computers are arranged as a redundant set, with each computer running the avionics software independently and simultaneously. Any one of these four computers may be designated as the flight control computer that actually controls and flies the shuttle. The four redundant set computers are linked as a "voting set." Each computer "votes" on the accuracy of the other three computers' computations. If the computers detect an error in one of the machines, they send a message to the mission commander, who may then deactivate the faulty machine.

The avionics software essentially flies and controls the orbiter. Functions include guidance, navigation, and control during each flight phase (that is, ascent, orbit, re-entry, and landing), and during contingency phases, such as abort. The backup flight software runs on the fifth on-board computer and can provide guidance, navigation and control during ascent, orbit, re-entry, landing or abort should the primary avionics software fail.

CONCERNS ABOUT CURRENT OPERATIONS AND SYSTEMS

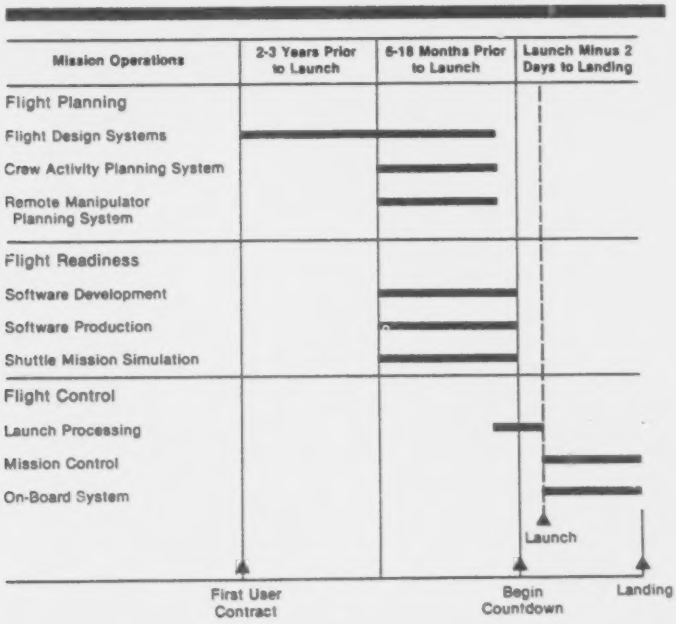
The existing operations and systems have been used to plan and develop 25 missions to date.[11] We noted concerns that current mission operations are not as effective or efficient as they could be. According to NASA officials, the growing obsolescence of the

current information system architecture is an underlying constraining factor to the overall performance of flight planning, flight readiness, and flight control operations. This obsolescence could force up mission operations costs, or limit the number and complexity of missions that can be flown, or both.

Operations concerns

On the basis of the STS experience to date, the planning, readiness, and control operations can take 2 or more years for a mission, depending upon the mission's complexity. (Figure II.3 shows a timeline for an individual mission.) Mission complexity is affected by several factors. For example, complex missions could involve a unique ascent/descent profile; a payload not flown before; extra vehicular activity; multiple payloads where the payloads have not previously flown together; rendezvous or multiple orbit changes; or the use of the remote manipulator system.

Figure II.3: Mission timeline



Flight planning can start as early as 2 to 3 years prior to launch and not be finalized until 4 months prior to launch. It can take up to 5 months to finalize flight plans after they have been generated. A September 1986 flight rate study[12] by Johnson indicates that, depending upon the mission complexity, existing flight planning and software development and production operations may not be able to support the flight rates that NASA currently plans for the next several years. NASA officials recognize that the time required for initial flight-to-flight reconfiguration and then later reconfiguration due to payload or flight plan changes needs to be decreased.

Unique parameters of the flight software have to be modified, or newly developed, from flight to flight. This includes modifying orbiter software, simulation software, launch software, and mission control software. For example, the requirements data for just a single new pressure measurement would include noting data limitations, identifying on-board wiring configurations, describing on-board and ground display formats, and specifying the method of

communicating the data between the orbiter vehicle and the ground. This is complicated by the fact that each orbiter is wired differently and that existing data bases may not include all data needed for each flight, requiring authorized Johnson personnel to manually input this requirements data. In addition, just to integrate the telemetry data tape with the shuttle data tape to produce a total software package for on board the shuttle requires 5 weeks. According to a Johnson official, this 5-week period will most likely be further lengthened to accommodate safety measurements.

System architecture concerns

According to several NASA officials, the current information systems architecture is a primary constraining factor to overall operational efficiency and effectiveness. While some major system components (primarily hardware) are 1970s and 1980s technology, the overall system architecture carries over many parts from Gemini and Apollo (1960s vintage) and was not designed for rapid, low-cost reconfiguration for high flight rates and/or increasingly complex missions.

The architecture design for the Gemini/Apollo information systems was based on the assumptions that the missions to be supported would have a long interval between flights (2-6 months), that the spacecraft to be supported would be relatively simple (compared to the shuttle), and that the total duration of the project would not be so long that the technology would become obsolete within the project's lifetime. The long mission interval meant that mission operations could be highly "labor intensive"--flight controllers could be expected to put in a couple of 50-60 hour work weeks during a flight without performance degradation, if they could have some time to recuperate and train before the next flight was scheduled. Also there would be ample time to reconfigure the software and hardware between missions. According to NASA officials, based on the then state-of-the-art technology, the labor intensive operations were the most cost-effective.

Hardware obsolescence was one area of concern identified by NASA officials. For example, according to NASA, the manufacturer of current Univac 1100/44 computers will discontinue maintenance support in 1990. Hardware obsolescence generally means lower reliability and increased operation and maintenance costs. Computer capacity shortages in all operational areas was another area of concern. Computer capacity shortfalls can constrain the flight rate and can also impede off-line real-time flight support, such as slower response time, and preclude the addition of new capabilities such as better simulation models which can improve crew training and increase flight safety.

In addition to hardware obsolescence and capacity problems, NASA officials expressed concern over the lack of user friendly software and the use of nonstandard operating systems and software. This makes software maintenance and modification very complex and implies larger personnel and training costs. Kennedy officials believe that the launch processing system software may become obsolete by 1992, making it impractical to continue using the system. The Kennedy system is reportedly a more modern system than Johnson's mission control center.

While it may be easy to recognize that hardware must eventually be replaced, it is more difficult to recognize that software also reaches the limits of its original design and the technology used to implement it. While there are no absolute rules on when to rebuild rather than maintain the existing system, the National Bureau of Standards has issued guidance[13] on this issue. Basically the Bureau identified several system characteristics which, if they exist, make the system difficult to maintain and potentially a candidate for redesign. These include the questions of whether (a) the system is a "mega-system" consisting of one, or several, very large (thousands or tens of thousands of lines of

code) programs; (b) the code is over 7 years old; (c) the code was written for prior generation hardware; (d) more than one programming language is used; (e) low-level languages, particularly assembly code, or unique languages are used; (f) very complex program structure and logic flow is involved; (g) there is difficulty in keeping maintenance programmers and analysts; and (h) the documentation is inadequate or out of date. NASA's STS software meets many of these criteria.

A 1981 Mitre study[14] on the obsolescence of air traffic control operations software offers insight into software obsolescence and its potential impact. Mitre concluded that the existing air traffic control software, which was developed in the early 1970s, was becoming obsolete and was not likely a suitable foundation for incorporating advanced automation. Mitre pointed out that the application code was written in a mixture of assembly code and a high-level, but obsolescent, language, which made the system difficult to maintain and modify.

According to Mitre, patches and modifications had caused the code to become very convoluted. Therefore, the Mitre study concluded, it would be extremely difficult to design software for advanced automation functions that would perform within the constraints of the current air traffic control software. Mitre also pointed out that these characteristics were not peculiar to just the air traffic control software but are believed to be a natural condition of any large software system that is used over a number of years without extensive restructuring.

There are some functional and operational similarities between the air traffic control operations software and the shuttle operations software. For example, similar to the STS operations software, air traffic control software performs real-time flight planning and flight control functions. STS operation software code, some of which dates back to the mid 1960s, is written in several unique and potentially obsolete languages. According to NASA officials, Johnson software has also been modified many times.

NASA's CURRENT MODERNIZATION PLANS

NASA has approved several projects for upgrading selected components of STS information systems and is examining the use of advanced automation to improve selected areas of mission operations. However, additional work is needed to determine if these projects fully address the growing obsolescence of the overall flight planning, flight readiness, and flight control operations and systems. For example, NASA does not yet have a single long-range architecture plan that integrates overall STS information systems used from the beginning of a mission to the end of a mission and which focuses on the obsolescence issue and how NASA is going to address it.

NASA has identified projects for upgrading various equipment components of the flight simulation, mission control, and on-board systems. These projects are divided into time phases. The initial phases focus on upgrades to alleviate short-term hardware obsolescence and capacity shortfalls. For example, NASA is currently upgrading the capacity of the mission simulation system. The agency has also replaced the central processors of the mission control system in order to improve reliability and reduce operation and maintenance costs. Later phases, if approved and funded, would replace the existing flight controller displays with higher-performance workstation technology that is intended to improve controller productivity and make controller training easier. At the time of our review, the later phases for the mission simulation system were not sufficiently advanced and were being studied further.

Some projects at Johnson are exploring the use of advanced automation software, such as expert systems to improve the

efficiency and effectiveness of mission operations. According to a NASA handbook,[15] an expert system is a computer program that performs at the level of a human expert in solving specific, rather than general, problems in specific situations.

Given the design of existing mission control systems, it is unclear as to how much automation can be incorporated in these systems. NASA officials have expressed concern that the design of existing operational software does not allow easy incorporation of new advanced automation features. A Johnson official estimated that only 10 to 15 percent of mission control operations could be automated, because of the existing mission control system design. We found no detailed NASA analysis that addresses the potential obsolescence of operational software at Johnson and Kennedy, or its impact on the integration of advanced automation features into the current or a future systems architecture.

In an effort to incorporate advanced automation into operations, Johnson staff have developed a language or tool to embed expert systems, which are written in specialized software languages, into conventional software and computers. Johnson has used this tool to develop four STS software applications, but none of these applications have yet been used on an actual flight. This new tool may potentially ease the integration of expert system software into existing software for some STS functions.

In October 1985 Johnson prepared a Statement of Policy for Integrated Data Processing--a top-level data processing policy to guide the development of a long-term automated data processing plan. The document includes broad policy statements regarding integrated information system architectures, but does not include an implementation plan and has not been formally adopted by the center. Based on Johnson's recently published information technology plan required by the Office of Management and Budget, it appears that Johnson has applied this policy primarily to financial and administrative systems and not to flight planning, flight readiness, and flight control operational systems.

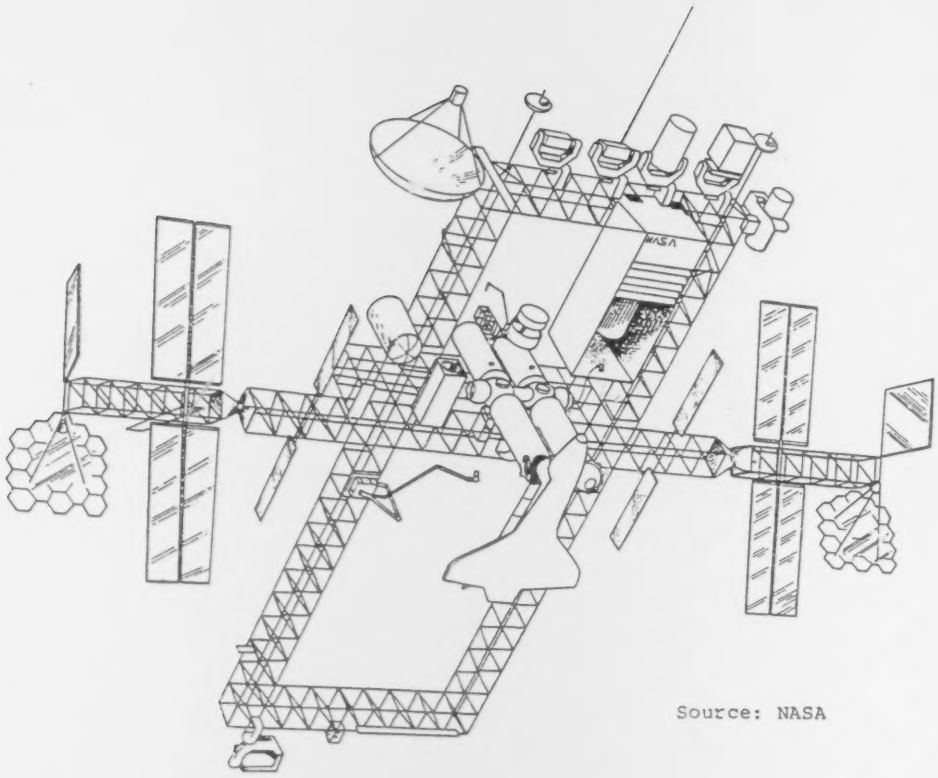
Johnson's Inspector General recommended in a September 1986 audit report that the center director formally adopt the policy statement and formally recognize both a Planning Council and Steering Committee for Integrated Data Processing that had been proposed in the 1985 policy statement. An interim Integrated Data Processing Steering Committee is studying how to implement the inspector general recommendations.

In January 1987, NASA announced that it was taking steps to place greater emphasis on long-range operational planning and system design for STS operations overall. In view of these steps, NASA and the Committee may wish to address several key questions, including:

-- To what extent, and at what cost, can the existing STS hardware and software support the number and complexity of missions currently planned?

-- To what degree can existing hardware and software support an effective and efficient assembly and servicing of a space station? and

-- What opportunities exist for using advanced automation and information technologies to improve STS' operations, and what is NASA's plan to incorporate these new technologies?



Source: NASA

SPACE STATION

According to NASA representatives, the Space Station is one of the most challenging projects that the agency has ever undertaken. NASA intends to move rapidly toward awarding the detailed design and development phase contracts. Successful development of the station will require NASA to recognize and solve many critical issues over the life of the project. According to NASA officials, determining the level of advanced automation[16] technology that will be needed to run the station efficiently and effectively, while containing both development and operational costs, is an important issue at this time. NASA documents indicate that acquiring the benefits of advanced automation will require complex research and development in information technology. We noted concerns by the scientific community and NASA representatives that efforts to plan for advanced automation and advance information technology are lagging, as compared to NASA's plans to design and construct the station, and have not yet progressed to the point that they will likely influence the station's design. As a result, concerns linger that the station's initial capabilities may include only limited advanced automation, and subsequent redesign of the station to incorporate advanced automation in an evolutionary manner could be extremely costly.

SPACE STATION: AN OVERVIEW

In January 1984, President Reagan announced a national commitment to develop a permanently manned space station. Some of NASA's objectives for the station are to provide

-- a national laboratory in space;

-- a permanent observatory;

-- a servicing facility for satellites and space vehicles;

-- a transportation node between low earth orbit and higher orbits;

-- an assembly facility for satellites, vehicles, and other large structures;

-- a storage facility; and

-- a staging base for missions beyond earth orbit.

NASA plans to implement the station program in the following five phases:

-- The concept phase (commonly called phase A), which states mission requirements and objectives, and articulates concepts that meet the objectives.

-- The definition and preliminary design phase (B), which selects the one concept that most satisfactorily meets mission requirements--within the constraints of cost, technology, and time.

-- The detailed design phase (C), which extends phase B to the point of preparing detailed engineering drawings and specifications for, among other things, the data processing systems.

-- The development phase (D), which will build and test the station components.

-- The operations phase (E), which includes the assembly and operation of the station.

As of February 1987, the Space Station program was in the preliminary stage of the detailed design and development phases. (For contracting purposes, NASA has consolidated the competition for these phases so that the contractors selected for the detailed design phase will also be responsible for the development phase.) On November 26, 1986, NASA issued draft requests for proposals to interested contractors.

NASA PROGRAMS TO DEVELOP INFORMATION TECHNOLOGY FOR THE STATION

NASA documents show that the successful development of information technology, including the use of advanced automation, robotics,[17] and high-quality software will play key roles in achieving program effectiveness and controlling life-cycle costs. Automation, if developed and implemented properly, can potentially improve both ground and on-orbit operations. The use of robotics will reduce risks to humans by performing hazardous tasks associated with space flight. The use of high-quality software is important to controlling software maintenance costs and will facilitate the eventual transfer of ground-based functions to the station.

NASA documents and studies by the scientific community affirmed that advanced automation can increase the systems' abilities to support innovation, allow the Space Station to operate autonomously, perform tasks unsuited for humans, reduce hazards to human life, increase crew productivity, and lower operating costs.

For example, on the basis of the Skylab and Shuttle experiences, individual crew members have about 10 productive hours per mission day. Of this, approximately 4 hours per day is used to verify and calibrate on-board instrument readings. NASA studies show that these activities could be accomplished by automation. To illustrate, studies conducted by TRW Inc. estimated that automation could reduce the crew time required to perform some satellite servicing tasks up to 60 percent. Regarding the actual implementation of advanced automation, it is important to (1) define the technology that will be required to automate a system or function, (2) plan the development of that technology, and (3) assess the likelihood that the technology will be sufficiently developed by the time it is needed.

NASA's Automation and Robotics Technology Development Program, the Space Station Information System, and the Technical and Management Information System are three key programs to develop and implement advanced automation and high-quality software for the station. The automation technology program addresses the development of the technology base for advanced automation and robotics, while the Space Station Information System and Technical and Management Information System projects deal mostly with system design and implementation, including the design of high-quality software.

Automation and Robotics Technology Development Program

On the basis of a concern that the agency had fallen 5 to 15 years behind in computer science and machine intelligence, NASA's Office of Aeronautics and Space Technology began efforts in 1980 to research artificial intelligence. In 1985, the office consolidated its automation and robotics efforts into a single program and initiated close coordination with the space station program.

In a March 1986 document,[18] the office stated that the focus of the 1980s is the development of technology to render space operations economically feasible for commerce and science. The specific objectives are to use automation and robotics to (1) reduce the cost of mission control (both ground support and astronaut time spent in housekeeping functions), (2) increase the operational capability of the astronauts by giving them the tools to enable the assembly, servicing, and repair of spacecraft distant from their base vehicle, and (3) increase the probability of mission success.

The program has a dual focus: the development of autonomous systems[19] and the use of telerobotics.[20] Development of each candidate application eventually leads to a practical demonstration. Underlying each focus is a core technology program that addresses sensing and perception, task planning and execution, control execution, operator interface, and system architecture and integration. Funding for the program in fiscal year 1986 was $9.6 million, or about .1 percent of NASA's overall budget. The office's automation and robotics budget plan for fiscal years 1987 through 1989 totals about $68 million.

Space Station Information System

The Space Station Information System is a term NASA uses for the information systems that are intended to provide information management from before the first launch of a space station component to well into the next century. The Space Station Information System must be able to provide systems control and data management on board the Space Station, as well as communications to and from the ground, all ground-based mission operations, and worldwide distributed processing of data for station users.

The system is supposed to support (1) prelaunch checkout, mission management, scheduling, and control; (2) software

development; and (3) the acquisition, transmission, recording, processing, accounting, storage, and distribution of data (including audio and video) produced by the station, its customers, and other space and ground elements interfacing with the station.

The software support environment is the first module of the Space Station Information System that NASA plans to implement. It is a collection of software, procedures, standards, hardware specifications, and training materials to be used in the life-cycle management of all operational Space Station software. It is not an information system that provides data processing services; rather, it is a set of methods, software tools, rules, and standards that establish the environment for Space Station software support. This system must be developed properly and become available when needed, in order to promote the design of high-quality software. NASA's Advanced Technology Advisory Committee points out that the software support environment should also provide those tools necessary to design and develop expert system software.

NASA released a request for proposal to develop the software support environment on September 11, 1986, with a contract award planned for May 1987. Johnson currently estimates that its development of the software support environment will cost about $287 million for fiscal years 1987 through 1993. As currently planned, the preliminary design review for the software support environment is scheduled for August 1988, about one year after contracts for the station's detailed design and development phase are awarded. NASA plans to have the fully operational software support environment available at the Space Station contractors' software production facilities in May 1991.

Technical and Management Information System

The Technical and Management Information System is defined as the integrated system of technical and management processes, automatic data processing hardware and software, communications, procedures, and people supporting the definition, design, development and operation of the Space Station program.

This system is planned to provide (1) the capability for exchanging technical and management information (for example, drawings and budgets) between all Space Station participants, including NASA centers and contractor locations; (2) 16 data processing capabilities (for example, word processing, computer-aided design) in support of 28 program functions, such as project management, technical analysis, and Space Station operations; and (3) the capability to archive and store program information throughout the station's operational life. NASA officials told us this system is a pilot program, which, if successful, could be expanded to support other NASA programs.

NASA's Advanced Technology Advisory Committee believes this system should also capture the "whys" or rationale that station developers use when making trade-offs during the design process. The committee has stated that this knowledge will be needed to support future operation of expert software systems.

NASA plans to acquire the system in four phases over a time span of about 10 years (February 1983 to December 1994). Each of the four phases will introduce additional system capabilities needed to support the ongoing phases of the Space Station project. The project is currently nearing the end of Phase 1. A set of five capabilities is in place, geographically dispersed, and not integrated (that is, the capabilities at one NASA center cannot easily communicate with those at other centers). These five capabilities are

(1) electronic mail and calendaring,

(2) program management and scheduling,

(3) documentation interchange,

(4) database storage, and

(5) limited computer aided engineering and computer aided design.

NASA plans to acquire the Phase 2 capabilities--a fully integrated set of 16 data processing functions--through the work of a systems integration contractor. This contractor is supposed to develop the detailed design and overall system architecture and perform the key task of integrating the system's components. The system will be fully operational at the end of Phase 2. The two remaining phases will provide updated capabilities in support of Space Station operations. NASA estimates that completing the system project will cost $325 million, using fiscal year 1984 dollars.

CONCERNS ABOUT AUTOMATION AND SOFTWARE

Several concerns have been raised about the development and implementation of both automation and high-quality software. NASA's Advanced Technology Advisory Committee (ATAC)[21] is concerned that automation planning is not progressing quickly enough to significantly influence station design. In a 1985 study,[22] the Office of Technology Assessment (OTA) has stated that the technology base in advanced automation will not move ahead rapidly enough and thus will hamper the Space Station's capability. NASA officials have expressed concern that the software support environment may not be ready for the initial station design stages and that the life-cycle costs of the Technical and Management Information System could be high if the system is built using off-the-shelf software packages that are not converted to the language which will be used for the Space Station Information System. These concerns are discussed in more detail below.

ATAC's concerns about automation planning

In 1985[23] ATAC issued its first report that identified advanced automation and robotics technologies that should be considered for the station. In that report, ATAC pointed out that NASA should establish--early in the Space Station operations planning process--quantitative criteria for analyzing automation requirements, life-cycle benefits and costs, and technical feasibility. These criteria would serve as a basis for identifying automation requirements, selecting automation candidates, identifying what automation technology to push, and when to push it. ATAC believed that NASA's biggest challenge would be to ensure that the criteria established appropriately balanced the potential life-cycle benefits of automation against the initial development cost.

ATAC also noted in its 1985 report that, although the station would not initially have significant on-board automation, it was critical that the station's design be flexible enough to accommodate future automation enhancements. ATAC explained, however, that much complex research and development of several advanced automation and communication technologies had to be addressed long before they could be used either for the station's initial or later configurations.

ATAC has continued to monitor NASA's automation and robotics efforts and provide progress reports to Congress semiannually. In October 1986,[24] ATAC issued its third progress report, which NASA delivered to the Congress on December 10, 1986.

Most of ATAC's concerns focused on automation. The report stated that although NASA's planned use of robotics looks promising, planning for some kinds of advanced automation technology was not progressing quickly enough to significantly influence station design. To underscore its concern, the committee noted that the results of automation work to date had not yet been incorporated into the design control documents which would be used for the detailed design and development phase requests for proposals. ATAC explained that the baseline configuration documents for the station's flight elements made scant, if any, mention of the evolution and growth considerations identified in previous committee reports. One exception was the Data Management System, a planned on-board system that is supposed to provide, among other things, network services for the other on-board systems. The system's design control document does, according to ATAC, address requirements for growth and incorporation of expert systems, although it lacked detail. The technical proof-of-concept for this system is scheduled to take place in 1988.

ATAC believes NASA's constraint to design the Space Station to an initial target cost without giving due weight to operational or life-cycle costs is the primary inhibitor of automation for the station.

On the basis of its concerns, ATAC urged NASA to

-- promptly prepare and approve a new automation and robotics process requirements document to cover the remainder of the definition and preliminary design phase and the start of the detailed design and development phases; and

-- include automation and robotics requirements, including design knowledge capture and life-cycle costing in the detailed design and development phase proposal requests, and that the proposal selection criteria place significant weight on these factors.

The committee recommended one of two alternatives to NASA: either set aside funding for advanced automation, or balance its consideration of operational (life-cycle) costs with the initial development costs when evaluating proposals submitted by contractors competing for the station's detailed design and development contracts. Without NASA's commitment to one of these alternatives, the committee reported that it expected to see very limited advanced automation on the initial station; an excessively costly process to incorporate evolutionary growth in advanced automation; a station that would be operationally expensive; and a station that could not support autonomous operation.

In transmitting ATAC's progress report to the Congress in December 1986, NASA stated that no firm conclusions had been reached on the appropriate level or timing of automation and robotics capabilities. NASA acknowledged that it had emphasized taking an architectural approach to satisfy a diverse set of users rather than emphasizing operational considerations and agreed that automation and robotics needed to be given a high priority in the detailed design and development phase procurement process.

NASA stated that it has requirements to ensure that the request for proposals address the importance of automation and robotics and also stress quality and quantity of automation and robotics applications. To give automation a more significant role in station design, NASA said that it had also appointed a Division

Director in the Office of Space Station with direct responsibility for automation and robotics.

Our preliminary review of the four NASA draft requests for proposals issued for the detailed design and development phase contracts supports ATAC's basis for concern about the design control documents. We noted that two design control documents that the Committee identified as important to the successful implementation of advanced automation and robotics were not updated for the detailed design and development phase proposals, and except for one instance, included as documents that would be binding on the contractors. For example, the Automation and Robotics Process Requirements Document, which provides the tasks and decision processes required to ensure adequate consideration of automation and robotics across the program, was (1) written early in the program, (2) not updated to cover the detailed design and development phase work, and (3) included as a binding document in only one of the four requests for proposals. Although contractors might use the document for reference purposes, its use is not binding on three of the four the contractors.

Another key document, a manual for the design of automation and robotics,[25] was not included as either a reference or binding document in the requests for proposals. ATAC believes this document is important because it provided guidelines and suggested approaches for

-- incorporating automation and robotics in the station design, and

-- considering the hardware and software design that would be necessary to integrate automation, robotics, and machine intelligence into the station design as these technologies become available.

At the time we prepared this report, NASA had delayed issuing the final proposal requests. Thus, we could not determine whether NASA had changed the requests to address ATAC's concerns and incorporate their recommendations.

OTA's concerns about the technology base

The 1985 OTA staff study, conducted at the request of the Congress, concluded that, unless NASA funds automation and robotics at levels substantially greater than currently projected, the Space Station would not include state-of-the-art automation, and its eventual evolution beyond its initial capabilities would be hampered.

These conclusions were based on OTA findings, which include the following:

-- NASA was not planning to use Space Station program money for automation and robotics research except in a few selected areas where it could not be avoided.

-- The only research NASA planned to undertake rested on the Office of Aeronautics and Space Technology program. (In 1985 the funding level for this program was about $8 million. A March 1986 document issued by that office indicated a fiscal year 1987 budget of $18 million.)

-- Unless NASA funds automation and robotics research at levels substantially greater than the current and projected levels, the generic technology base in advanced automation and robotics was likely to hamper Space Station capability beyond its initial operations capability.

-- NASA's investment in generic technology base advancement and application engineering was believed likely to be recouped in eventual savings in the station's operational costs, which loomed as a major funding problem for the space station.

-- There was little need for further concept studies in automation and robotics. Aggressive research should be initiated without further delay.

NASA's concerns about the development of high-quality software

NASA officials at Johnson believe one of the biggest challenges facing them in developing the software support environment is a timing problem. Specifically, the software support environment contract is not scheduled to be awarded until May 1987, and the actual design of the system is not scheduled to be baselined until May 1988. However, the design, development, test and evaluation contracts for the station as a whole are scheduled to be awarded in August 1987. This will require NASA to either provide an interim software support environment capability so that the station contractors can begin initial requirements definition, or accept the contractors' proposed procedures for software design until the actual software support environment is baselined. In either case, the contractors will need to make a transition to the final software support environment when it becomes available.

Another challenge faced by Johnson is that the software support environment project must develop and test verification models that will function with simulation routines for various space station work tasks. Officials at Johnson noted that past experience in the shuttle program has shown that developing these models was difficult for some tasks.

According to project officials at Johnson, the greatest single risk to the technical and management information system project is a potential lack of management support for the project through failure to commit adequate staff resources. As stated in its July 1986 report, NASA studied and consulted with private industry regarding how many staff would be needed to accomplish the project within its established timeframes. The results of that study suggested that 80 to 90 full time staff would be required, including both NASA and contractor employees. Project officials stated that only 40 to 50 people were working on the system as of November 1986. When the results of this study were presented to the project Planning Council, the council stated that assigning 80 to 90 people would be difficult. The issue of adequate management support for the project was also identified by a non-advocacy project review team in its September 4, 1986, report.

According to project officials at Johnson, integrating the 16 system capabilities with each other will be the most difficult technical challenge for the program. For example, the officials cited difficulty in finding a commercially available software package that would provide integrated word processing and image processing capabilities. Each of these capabilities is easily found separately, but an integrated set is not readily available, according to project officials. An integrated set of capabilities would allow the display and manipulation of both text and graphics on the same screen.

Choosing and integrating software written in different computer languages will pose another technical challenge for the project. According to a project official, the system will be built initially using commercial-off-the shelf software, typically written in the COBOL or FORTRAN computer languages. Although Space Station computer systems are planned to use the developmental language Ada, NASA plans to build the technical and management

information system using available technology so that less development will be needed and the system will become operational sooner. As commercial software packages that perform the same functions become available in the Ada programming language, NASA plans to convert to such packages.

A NASA computer consultant that we were referred to by Johnson officials stated he has two concerns regarding this strategy. First, technical problems may arise when interfacing the technical and management information system (which will probably not be written in Ada) with the other Space Station information systems (which are supposed to use Ada). However, the consultant stated that these were not insurmountable challenges.

Of greater concern to the consultant was the potential for greatly increased system life-cycle costs if the planned conversion of the system to Ada does not occur. The consultant stated that one quality of the Ada language is its relatively low long-term software maintenances costs. He contrasted this to the computer languages COBOL and FORTRAN, stating that these languages typically incur high long-term software maintenance costs. According to the consultant, computer systems using COBOL and FORTRAN typically incur 90 percent of their life-cycle costs after the system becomes operational. This phenomenon is due to the high cost of maintaining the software written in these languages. According to the consultant, if NASA does not convert the system to Ada within approximately 4 years of the date when its initial Phase 2 capabilities become operational, the system's life-cycle costs, driven by increasing software maintenance expenditures, could become prohibitively high.

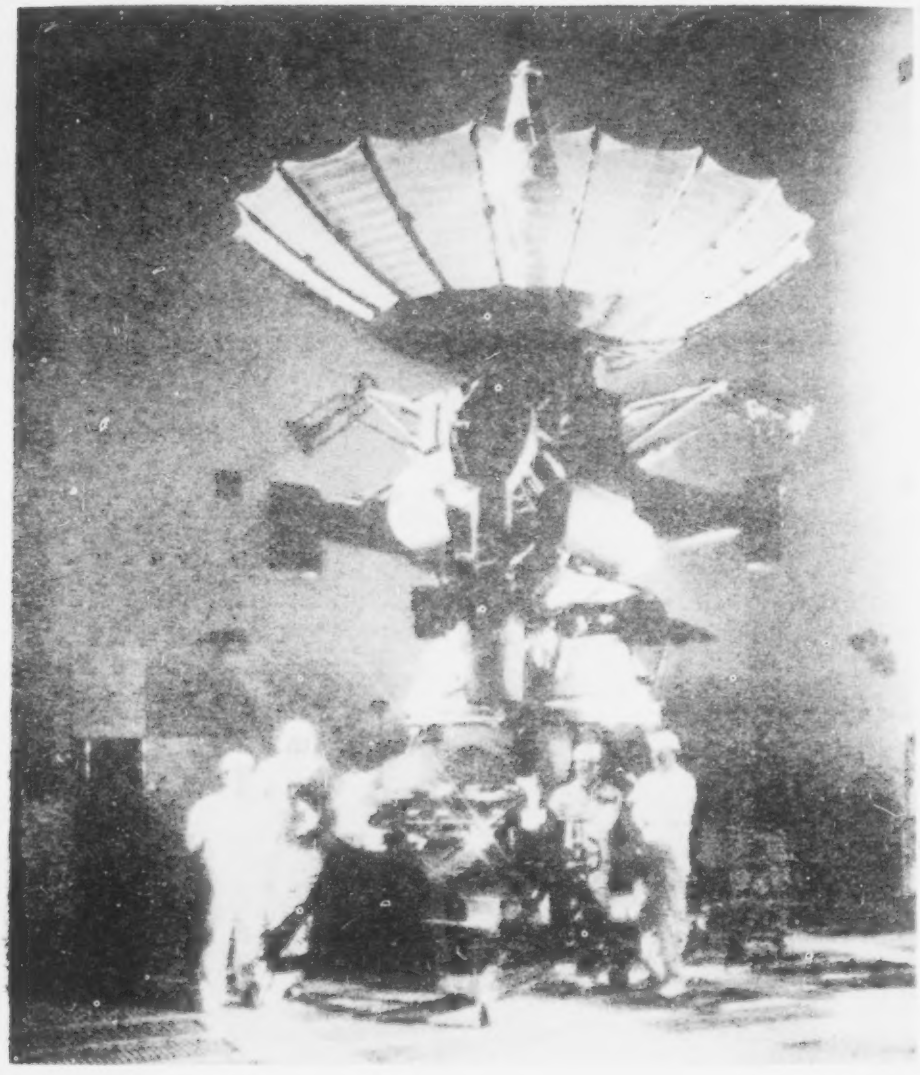
NASA may soon be making important trade-off decisions that could significantly affect the cost and operational capabilities of the station, possibly for its estimated life span--30 years. In light of the large investment that the Space Station will likely require, NASA and the committee may wish to consider addressing several key questions including:

-- If NASA remains committed to its cost and timeframe goals for designing and developing the station, will it have to use a "minimal risk approach," which would involve, in large part, the use of existing technologies for most station systems?

-- If a minimal risk approach is taken, will this force NASA to rely primarily on proven, existing information technology that may be seriously outdated by the time the station is placed in operation?

-- Will NASA be incurring the risk of building a less effective station with excessive operating costs and extensive dependence on ground stations for its long life?

 APPENDIX IV



Source: NASA

UNMANNED SPACE PROBES AND SATELLITES

In addition to its manned space missions, NASA has a goal of extending the frontier of scientific knowledge about space through unmanned exploratory missions to survey the earth, our solar system, and the universe. These various missions produce a set of scientific data that is transmitted to earth for processing and analysis within the space science community.

Information technology (hardware and software systems) provides essential support to three major operational areas: telecommunications, space science data management, and space flight control operations. NASA does have on-going programs to improve operations in these areas. On the basis of our limited review, we have identified concerns in all three areas that might require NASA

to consider further actions. For example, in telecommunications, NASA's space network may not have sufficient capacity to handle data transmission requirements once the space station is in operation. Similarly, NASA may not have adequate storage, cataloging, and processing capacity to handle the very large amounts of space science data expected in the near future. Finally, NASA may not have adequately determined the best method for making space flight control operations more efficient.

TELECOMMUNICATIONS SYSTEMS

Once space science data are acquired by a probe or satellite, the data must be accurately transmitted to Earth for analysis by scientists. In addition, data which record the health and status of the probe or satellite itself must also be accurately transmitted. NASA has two telecommunications systems, the space network and the spaceflight tracking and data network, that provide data transmission services for spacecraft flying in a low Earth orbit. A NASA study shows that the baseline space network, configured with only two satellites as is planned, may not be sufficient to handle data transmission requirements once the Space Station is in operation. Furthermore, ground-based communications networks also may be unable to handle the increased traffic.

The space network is a space-based system that uses high orbiting satellites, called tracking and data relay satellites, to relay communications between ground stations at White Sands, New Mexico, and low Earth orbiting spacecraft. These relay satellites do not process communication signals but simply relay them between the ground station and the spacecraft. Currently only one tracking and data relay satellite is in orbit; two more will be launched as soon as the shuttle resumes flights. This program has experienced difficulties, including degradation of the capabilities of the one existing satellite and the loss of a second satellite in the Challenger accident.

The baseline space network will be complete when two operational and one spare satellite are in service. When it is complete, the space network is planned to replace the older, ground-based spaceflight tracking and data network. NASA plans to rely on the space network to relay data, commands, and telemetry between low earth orbiting spacecraft and the ground.

From NASA documents, it appears that the two-satellite baseline space network may not be adequate to handle the conflicting telecommunications needs of the space station, the shuttle, the Hubble Space Telescope, and all other low Earth orbiting spacecraft. The two-satellite configuration will provide only four high-rate transmission channels at a time. The Space Station will occupy at least one channel constantly and will tie up two channels when it "transitions" (switches from one satellite to the other). Any ongoing shuttle flight will also occupy one channel and tie up two when it transitions. The space telescope is expected to require at least 30 minutes of high rate transmission per orbit, and other satellites and experiments may also intermittently require high rate transmission.

NASA has a long-range plan to add an additional two tracking and data relay satellites (for a total of 5) in the early-1990s to meet the increased telecommunications demands of the Space Station. However, NASA's ability to place four active and one spare satellite in orbit by the mid-1990s will depend on several factors, including manifesting two satellites on dedicated shuttle flights in 1990 and 1991, and successfully placing a total of five satellites in orbit without any degradation of capabilities, as has been experienced with the one satellite currently in orbit.

In addition to the potential limitations of a two-satellite space network, telecommunications capacity may be further limited by the capabilities of the systems that are used for transmitting

data among different NASA locations. NASA uses two systems for these functions. One, called NASCOM, transmits science and telemetry data. The other, called the Program Support Communications Network, carries program-level information. A NASA program official told us that these systems are already close to being overloaded. Any further demands, such as those the space station will make, may only worsen the situation.

SPACE SCIENCE DATA MANAGEMENT

Because the major product of NASA's unmanned space missions is scientific data, the scientific community has paid much attention to how well NASA has managed the areas of processing, distribution, and archiving of the space science data. Concerns in these areas have been addressed in detail by the Committee on Data Management and Computation (CODMAC), which was formed in 1978 by the National Academy of Sciences' Space Science Board. NASA has responded to the concerns with a program to provide computing resources and manage data that is funded at about $20 million per year. This program has addressed some of the scientific community's concerns. However, scientists expect space data to be generated at a far greater rate by the end of the decade than has ever been produced in the past. More advanced data collection techniques and more complex scientific instruments, such as the space telescope, will markedly increase the amount of data returned to earth.

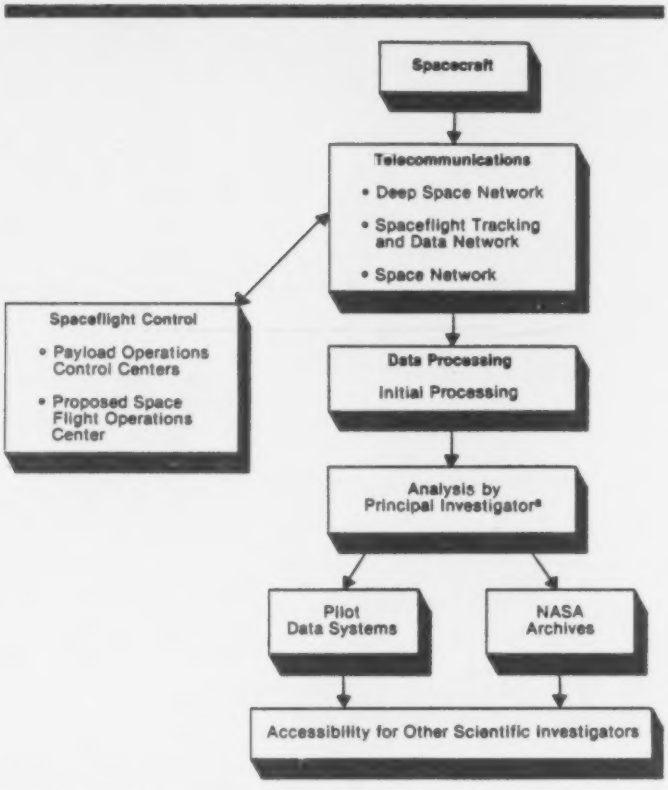
CODMAC concerns about data management

In its 1982 report,[26] CODMAC concluded that (1) there was insufficient involvement of scientists in the data management process, (2) data analysis funds were inadequate and often were reprogrammed due to hardware overruns, (3) NASA had not exploited or implemented current data system technologies, (4) a responsible scientific group for data management during and/or after missions was often not clearly identified, and, (5) the method NASA generally used to distribute, store and communicate data limited the efficient extraction of scientific results from space missions. To improve data access and quality, CODMAC recommended use of software standards, more emphasis on data documentation, use of more modern technology, more frequent updating of computing facilities, and active involvement of scientists in the planning, acquisition, processing and archiving of data in order to maximize the science return.

CODMAC expressed concerns that scientists were unable to access data in a timely manner from NASA satellite missions, and when the data was accessible, it was often of poor quality. Figure IV.1 depicts the end-to-end flow of scientific data from the spacecraft to final analysis and archiving, showing the major, and sometimes time-consuming route that information must take before it is available to the general scientific community.

Generally, the scientist in charge of any given mission (called the principal investigator) would get pre-processed spacecraft data from NASA (although it might take a few months). The principal investigators were supposed to return the data to NASA data centers for archiving after it was processed and fully documented. However, the principal investigators often did not do this--making it difficult for other scientists to access the data. Also, data that was sent to the centers was often undocumented, so that data was often unusable for other investigators. For example, data was compiled in many different formats because there were no data standards. As a result, users spent considerable effort in understanding or modifying the formats. Further, it was often difficult, if not impossible, to correlate data from multiple sources and it was often not well known or publicized within the scientific community which data were archived at the data centers.

Figure IV.1: Space science data flow



[a]At This Stage, the Investigator Has the Option of Using NASA's Computer Facilities.

CODMAC also noted that the archives had inaccurate or insufficient information concerning the quality or limitations of the data. For example, important supporting data, regarding the spacecraft's exact position in orbit at the time the data was acquired was often missing. Since there were often no plans to determine what should be done with data after missions were finished, some of the data tapes, which now contain irreplaceable information, could lose their ability to be read by a computer and thus become worthless.

CODMAC attributes these problems to its belief that archiving data was not a priority because most of the project funding was used for building spacecraft instruments. As a result, almost no consideration was given to documenting and forwarding the data to NASA.

In March 1987, CODMAC issued a second report[27] detailing continuing concerns about space science data management. The report stated that NASA still lacked an overall vision as to what requirements scientists would have for NASA systems to handle, process, and store the significant quantities of data expected from future missions. The committee stated that the rapid growth of data and the wide geographic distribution of scientific facilities would present especially troublesome problems for data archiving, distribution, and analysis.

NASA activities addressing CODMAC concerns

Since CODMAC first expressed its concerns in 1982, NASA initiated several data archiving projects. These projects include specialized information systems called pilot data systems covering the planets, oceans, land science, and climatology.

CODMAC has supported the pilot data system projects and has cited the planetary data system in particular as a good example of a partnership between NASA and the scientific community involving a decentralized, rather than NASA-centralized system. However, management of space science data as a whole may still be an area of concern because the pilot data systems only address limited subsets of the available data.

NASA has studied the idea of developing a single integrated system that would provide space science data and applications resources to all users. However, the Science and Applications Information System, as it would be called, is only a concept at this point. NASA has not yet committed to funding this large system, which could cost $350 million, but is planning, on a smaller scale, to integrate the climate, ocean, and land data systems into an Earth Observation Information System.

Magnitude of data collection in the near future

The magnitude of data that will be produced in the near future is expected to be much greater than present day amounts. CODMAC reports that space science data are expected to double in quantity roughly every 2 to 5 years. The scientific community is concerned about processing and archiving such a large amount of data. For example, the planned earth observing system program representatives estimate that they will have to process and store approximately 10 trillion bits of data per day. If that data were to be stored on standard magnetic tape that held 6,250 bits of data per inch, it would require enough magnetic tape to encircle the earth each day.

While no one, to our knowledge, has proposed using magnetic tape to store this data, this illustration points out that there must be considerable advances in data storage technology in order to handle the massive amount of data being projected. For example, even using current optical disk storage technology, the Earth Observing System alone would require approximately 5,000 disks each day to store the data, with each disk storing 2 billion bits of data.

Data collection requirements in the Space Station Era

The Earth Observing System example does not include the additional data transmission, processing, and storage requirements of the Space Station scientific instruments (potentially on the order of three trillion bits of data per day) or ocher scientific instruments such as the Hubble Space Telescope. Another issue that has been raised with the advent of such high data rate instruments is the ability of on-board recording devices to record the data when the instrument is unable to transmit the data through NASA's telecommunications system. A July 1986 MITRE Corporation report[28] pointed out that the state-of-the-art space-qualified recorder currently being developed by RCA Corporation will only have approximately 4 percent of the capacity being specified for NASA's planned polar orbiting platform recorder. Further, the report stated that the new recorder will only be able to record that data at a fraction of the required rate.

NASA efforts to improve scientific computing resources

NASA has attempted to increase scientists' access to its computational centers, primarily the Space and Earth Sciences Computing Center at the Goddard Space Flight Center, for processing

space science data. During fiscal year 1987, the center will begin planning to acquire a next generation supercomputer, to be delivered in January 1990. A recent NASA Advisory Committee Report also recommended that Goddard obtain a supercomputer by 1989 with at least 15 times the power of its current computer.

The scientific community has also expressed a need for supercomputer capabilities. A Jet Propulsion Laboratory (JPL) survey of its scientific community found that 44 of 154 respondents had specific needs for a supercomputer, totaling about 70 hours per week. Reportedly, these needs could not be met elsewhere. Further, of the 110 respondents who indicated no definite requirement for a supercomputer at JPL, a significant number were meeting their needs at other NASA computer centers.

NASA officials have suggested there are other alternatives to installing more supercomputers. One alternative was to upgrade the current facilities to improve scientists' remote access to existing supercomputer centers. Another alternative was for scientists to include these computing resource needs as part of their grant proposals. From an economic viewpoint, NASA officials stated that the high cost of acquiring supercomputers was a reason for not placing one in each NASA center.

EFFICIENCY OF SPACEFLIGHT CONTROL OPERATIONS

NASA has been criticized by the scientific community for duplication of effort in establishing multiple mission control centers for unmanned satellites and probes instead of consolidating these efforts. In addition, NASA has expressed concern about the age of its hardware and systems for unmanned spaceflight control. A potential solution for both problems has been planned, through the consolidated Space Flight Operations Center, scheduled to be completed at JPL in 1990.

At the present time, individual unmanned spaceflight control operations centers manage a variety of "housekeeping" (routine) functions that allow a satellite to carry out its mission. For example, a satellite must be tracked constantly to ensure that it is on the proper course, and retrorockets must be ordered to fire to correct deviations in course or in the attitude of the spacecraft with respect both to Earth and the subject it is investigating. In addition, the spacecraft's energy management, communications, and data recording systems must be monitored and kept healthy. NASA now relies largely on multiple control centers to perform these routine functions. Each center usually has its own computing equipment, as well as personnel resources.

NASA Advisory Council concerns

The Solar System Exploration Committee, an ad hoc committee of the NASA Advisory Council, was organized in 1980. It established a Mission Operations and Information Systems Subcommittee to assist in identifying ways of lowering costs for planetary mission operations. The overall function of the subcommittee was to provide a critical assessment of current efforts to achieve lower cost mission operations, to recommend further studies and development, and to provide oversight of ongoing JPL activities in these areas.

The subcommittee reported that mission operation cost growth had been compounded by several factors, including (1) the need to develop unique operations and information systems for each planetary mission (2) gradual antiquation of existing ground data systems characterized by labor-intensive operations and high maintenance costs, and (3) insufficient end-to-end analysis of the complexities of deep space mission operations, including the handling of large volumes of data from many instruments.

The subcommittee concluded that the primary cost for planetary mission operations was staffing. Ways of reducing staffing expense included (1) using advanced automation, in the form of expert systems, to replace some labor-intensive tasks with computer models and tools, (2) developing data standards to simplify the mission operation process and encourage sharing of personnel across projects, (3) developing common software for such tasks as sequencing and data records. Furthermore, the subcommittee stated that a key factor in achieving lower cost mission operations was the design, development, and implementation of an integrated Space Flight Operations Center.

The Space Flight Operations Center project is reportedly addressing many of the concerns expressed by the subcommittee. The project is a 5-year effort to develop and bring into operation an upgraded operations control center at JPL. According to NASA documents, the center will utilize up-to-date computing, networking, and data management technology to meet the requirements for flight project support. The overall goal of the project is to develop a control center design which will make implementation and operations for future flight projects more cost effective. The project is currently scheduled for completion in July 1990.

Considering the financial and human investments that are being made by NASA and the scientific community in the unmanned space area, NASA and the committee may wish to consider addressing several key questions including:

-- What specific action is NASA taking to ensure that its space and ground based telecommunications systems will be able to handle the massive amounts of scientific data that it anticipates processing in the future.

-- What plans does NASA have to insure that its ground facilities will be able to adequately communicate, process, distribute, and archive such volumes of data from satellites and other systems like the planned Earth Observing System, in a high quality manner?

-- Although NASA is taking steps to make space flight operations control more efficient, what potential exists for using advanced automation in on-board satellite systems to alleviate some of the burden of managing routine functions that are now controlled from the ground? Further, how much would using this strategy, in conjunction with more efficient ground operations, reduce overall life-cycle costs?

NASA's USE OF INFORMATION TECHNOLOGY

NASA was established in 1958 as an independent agency responsible for conducting space and aeronautical activities for peaceful and scientific purposes. Some of NASA's specific objectives, as stated in its fiscal year 1987 budget, are to

-- make the agency's Space Transportation System--of which the space shuttle is a key part--fully operational and cost effective,

-- move toward the establishment of a permanently manned space station,

-- conduct an effective and productive space and earth sciences program, and

-- conduct effective and productive space applications and technology programs.

In performing its mission, NASA relies heavily on information technology and spends about 10 percent of its annual budget on this technology. NASA officials told us that $784 million was allocated for information technology in fiscal year 1986, out of a total agency budget of $7.8 billion. According to the Office of Management and Budget, NASA is planning to acquire more information technology over the next 5 years than almost every other federal civilian agency. The agency's long-range plan for fiscal years 1987 through 1991 lists 460 projects costing $1 million or more over this five-year period, totaling $4.1 billion. These projects fall under several categories, as shown in Table V.1.

NASA has two organizations that oversee the use of information technology: the Information Resources Management Division (within the Office of Management) and the Software Management and Assurance Program (within the Office of Safety, Reliability, Maintainability, and Quality Assurance).

The Associate Administrator for Management is responsible for issuing policy guidance on the management of information technology. One form of this guidance, a handbook that is reviewed annually and updated as needed, lists procedures, policies, and responsibilities for the planning and acquisition of such technology. This provides agency-wide guidance for planning the development of information technology and monitoring hardware and software acquisitions.

Additionally, the Office of Management prepares an annual long-range plan, which contains proposed resource acquisitions for the next 5 years. This plan is not regarded by NASA as a commitment document, and the numbers it contains are subject to change.

The goal of the Software Management and Assurance Program is to promote the acquisition of quality automated systems through sound software management principles. The program, which is based on efforts that began in 1980, is preparing a large package of software management aids that includes policy, guidelines, standards, and training. Two policy directives are in draft, one specifying requirements for software management planning and the other specifying required review procedures within different software categories. A set of guidebooks, directed at program and project managers, describes how to go about such tasks as acquiring software and managing software configuration. Many of the program's standards being developed and issued are based, in large part, on existing Department of Defense and European Space Agency standards.

Table V.1: Major NASA Information Technology Projects--Fiscal Years 1987 through 1991

Category	Number of projects	Estimated cost (thousands)	Percentage of total cost
Aeronautical research and technology base	126	$856,932	20.96
Space transportation operation program	45	$701,420	17.15
Space science and applications	73	$607,217	14.85
Shuttle production and operations program	55	$549,515	13.44
Space and ground network communication and data systems	44	$357,362	8.74
Launch and landing operations	13	$297,446	7.27
Resources and program management	38	$215,039	5.26
Space station	22	$176,965	4.33
Tracking and data acquisition	12	$140,020	3.42
Flight operations	15	$118,487	2.90
Other	6	$32,230	0.79
Orbiter	7	$30,194	0.74
Space research and technology base	3	$3,856	0.09
Life science	1	$2,388	0.06

OBJECTIVES, SCOPE, AND METHODOLOGY

We performed our work at the request of the Chairman, House Committee on Science, Space, and Technology. Our objectives were to obtain, analyze, and provide information to the committee related to three areas of information technology usage within NASA: (1) NASA's planning and development of data processing and automation technology for the Space Station, (2) NASA's modernization of information technology for the shuttle program, and (3) NASA's information technology for unmanned space exploration. Additional work is necessary before we can reach final conclusions, or make recommendations, on the topics discussed in this report. However, as requested during subsequent progress briefings with subcommittee staff, we also sought to identify potential issues regarding these areas that we believed may warrant further study.

Our work covered the period between July 20, 1986, and December 12, 1986. Where possible, we have updated the status of the information in this report through February 1987. We also reviewed and included information from a March 1987 report by the National Research Council.

We obtained the information for this report from pertinent management, technical, and contract information provided by NASA. We also held discussions with NASA representatives responsible for the direction of the automation support for these programs. We conducted our work at NASA headquarters in Washington, D.C., and at selected NASA field locations including Goddard Space Flight Center in Greenbelt, Md., Jet Propulsion Laboratory in Pasadena, Cal., Lyndon B. Johnson Space Center in Houston, Tex., John F. Kennedy Space Center, Fla., and White Sands Test Facility in Las Cruces, New Mexico. We also visited the University of Colorado, at Boulder, to discuss satellite control operations it was performing under contract with NASA. To identify potential issues, we reviewed pertinent technical studies and reports published by companies under contract with NASA, and by private sources.

During our review, we obtained the views of responsible NASA officials and program representatives nationwide and have incorporated their comments in the report where appropriate. We obtained written NASA comments on a draft of the report on April 9, 1987. These comments and our evaluation are in appendix VII.

We performed our work in accordance with generally accepted government auditing standards.

COMMENTS FROM THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Note: GAO comments supplementing those in the report appear at the end of this appendix.

NASA
National Aeronautics and Space Administration
Washington, D.C. 20546

APR 9 1987

Reply to Attn of: NTD

Mr. Frank C. Conahan
National Security and International Affairs Division
United States General Accounting Office
Washington, DC 20548

Dear Mr. Conahan:

Thank you for the opportunity to comment on the General Accounting Office (GAO) draft report entitled, "Computers: NASA's Use of Information Technology for Space Operations" (GAO Code 510174).

In large part, this report presents a correct picture of NASA's use of automated information technology in support of space operations. However, there were several areas which we do not believe were properly addressed in the report. First, the report does not adequately address the current and planned ground systems support for NASA missions. Second, there is an incorrect assumption about the final Space Network configuration for the Space Station era. Comments on these areas are contained in enclosure 1. Also, the report includes several expressions of concern about the progress the Office of Space Station is making in including Automatics and Robotics (A&R) into the Space Station design. These concerns are linked to the latest (December 1986) Advanced Technology Advisory Committee (ATAC) report. Enclosure 2 is a copy of a letter from the NASA Administrator to the Honorable Edward P. Boland which provides an accurate representation of NASA's views regarding this ATAC report and resulting actions planned or taken. We believe consideration of these comments will enhance the final report.

See comments 1, 2, and 3.

See comments 4 through 7

See comments 8 through 12.

Sincerely,

June Gibbs Brown
Associate Administrator
for Management

Enclosures

Enclosure 1

GROUND SYSTEMS

See comment 1.

This report does not adequately address the Communications and Data Systems Division's current or planned ground systems support. Traditionally, Managers of the Ground Support Elements (Networks, Control Centers, Data Processing, Flight Dynamics, Frequency Management) work closely with the projects (Space Transportation System (STS), Spacelab, Hubble Space Telescope, Space Station, etc.) to understand the mission requirements, frequency used, real-time and non real-time communications circuits, data rates, data delivery, spacecraft control, command management, maneuvers, orbit/attitude, schedules or planning functions, and requirements. The Ground Systems Managers ensure that systems provide the optimum support before, during, and after the mission to make sure that NASA and the scientific community receive support via the most efficient, cost controlled systems.

There are areas throughout the report which fail to address some of the accomplished or planned Ground Systems improvements to meet new requirements for future missions. Some of the accomplished or planned implementations are as follows:

See comment 2.

- The STS and Shuttle Attached Payloads - In our NASA Communications (NASCOM) and Program Support Communications Network (PSCN) areas, we have added the required real-time and administrative circuits to ensure mission success at the time needed. We have instituted procedures to install/delete communication links where it is cost effective to NASA. We know that these two networks require upgrades to meet the extremely high data rates and demands during the Space Station era and appropriate plans are being made.

See comment 1.

- Spacelab Missions Specifically - We have determined that the mission support requirements could not be satisfied by any existing system and participated in NASA "Joint Center Buys" for some high speed front-end equipment and separately procured other hardware and software elements/subsystems to successfully and jointly (Marshall, Johnson, and Kennedy centers, the Germans, European Space Agency, etc.) support the Spacelab 1, 3, 2, and D-1 missions as well as the Shuttle Imaging Radar - B (SIR-B) Payload. Our intense and continued effort is to ensure that Data Processing Systems can flawlessly capture Spacelab Data at the 48-50 MBPS rate, process and deliver products to users within an agreed to time period.

See comment 1.

- Hubble Space Telescope - We have successfully implemented a system to process the packet telemetry science data which this spacecraft will generate and are well on our way to completing the Control Center and other mission management functions. The packet telemetry concept is excellent from a science data handling systems point of view, continued changes and problems yet to be resolved on-board the spacecraft are transparent to the Ground System.

See comment 1.

- Space Station - We have plans and studies underway to implement a Ground System for this era which contains a Data Handling Center for science data, a Platform Control Center for both platforms, a Spacecraft (S/C) Servicing Center, Carrier and Instrument Control Centers for supporting users remote to the platform control areas, and a Flight Tele-robotics Support capability. The Office of Space Operations systems are important and integral elements of the Space Station Information System (SSIS) and our planning is being adjusted to reflect the latest Administration changes regarding Space Station development.

- Automation and Expert Systems - We will evaluate the applicability of these concepts to the Ground Systems for efficiency and cost reductions. We know that artificial intelligence/expert systems implementation is vastly different from contemporary systems.

- High Data Rate/Volume Missions - We have very large scale integration (VLSI) studies and techniques to build disc farms, and study activities with vendors to understand tape coating problems which when solved could provide on-line or off-line archive capabilities for large volumes of data. The high data volume topic is not new to us. In 1975 we were using tapes which held 60-70 times the data volume of conventional tapes. Our Spacelab Data Processing Facility used for the first time for Spacelab-1 support uses tapes having a packing density of 27K BPI in contrast with the 6250 BPI tapes indicated in the report.

See comment 3.

- Control Centers - Where appropriate to meet heavy mission demands a single or stand alone control center was built. However, where appropriate, we are supporting up to seven S/C in one Control Center and plan to increase this number to ten as the immediate future missions come on-line. During the Space Station era our Control Center will support Remote Operations Centers (ROC's), Discipline Operations Centers (DOC's) and User Operations Facilities (UOF's).

See comment 1.

- Standards and Data Distribution - We are familiar with the standards developed by NASA personnel participating in the Consultative Committee for Space Data Systems (CCSDS) Workshops for improved receipt, processing and distribution of data to users. This activity covers the end-to-end requirement from the on-board sensors to the user in his remote facility.

See comment 1.

- Studies and Technology - Currently we have approximately 30 active studies for systems which will be used for providing Space Station era support. The studies cover topics such as computer languages, navigation, system implementation management, expert systems, modeling, etc. We are very much aware of software and system development problems for contemporary systems and have a close relationship with Technical Management Information System (TMIS) and Software Support Environment (SSE) activities proposed by the Space Station office and how our respective systems will mutually benefit from these implementations regarding common languages, tools, software modules, etc. We participate in the Software Management and Assurance Program (SMAP) Steering Committee and have been involved in the development of its various software management documents.

SPACE NETWORK

The issue/concern identified by the General Accounting Office (GAO) for the Space Network is based on an inaccurate assumption regarding the Space Network configuration for the Space Station era. The issue/concern is that the Space Network capacity may not be adequate to handle the users' telecommunications needs once the Space Station is in operation. The inaccurate assumption is that the Space network final configuration consists solely of three satellites (two active, one spare).

A summary of the Space Network portions of the report has been provided and comments which clarify the Space Network configuration and present the Space Network plans to assure sufficient capacity to meet the telecommunications needs of the Tracking and Data Relay Satellite System (TDRSS) user community. We believe these comments satisfactorily resolve the Space Network issue/concern raised by the GAO.

Summary of Space Network Portions of the Report

Pages 12-13, 69-72

The issue/concern identified by the GAO is that the Space Network capacity may not be adequate to handle the telecommunications needs of the Space Transportation System, Space Station, and all other low earth orbiting spacecraft, and could result in significant losses of scientific data (pages 12, 12-13, 69, 70, and 71).

The following GAO statements leading to this issue/concern are in error:

> ... NASA plans to rely on a space network of three satellites (two active and one spare) to relay data between all low earth orbiting spacecraft and ground stations (page 12).

See comment 4. ... the space network, configured with only two satellites as planned (page 70).

See comment 4. ... The space network will be complete when two operational and one spare satellite are in service (page 70).

See comment 5. ... At the present time, NASA is no longer actively pursuing the plan to deploy two additional satellites (page 71).

Pages 14, 83-84

One of the GAO suggested key questions (for NASA and the Committee on Science, Space, and Technology) involves the Space Network:

> "What specific action is NASA taking to ensure that its space-based telecommunications system will be able to handle the massive amounts of scientific data that it anticipates?"

NASA Space Network Comments:

The projected launches of two Tracking and Data Relay Satellites (TDRS's) in 1988 when the Shuttle flights resume will complete the initial baseline Space Network configuration. The operational baseline Space Network configuration will be established subsequent to the launch of a third TDRS (planned for 1989), when three fully functioning spacecraft (two active, one spare) are in their geosynchronous orbit positions. We have determined that the Space Network baseline configuration will have the necessary capacity to support TDRSS users through the early 1990's.

Our mission model analyses, during the past few years, for the Space Station era, which we have assumed as beginning in the mid-1990's, have indicated that two additional active TDRS's may be needed to accommodate the TDRSS users' scientific and engineering support requirements during this period.

See comment 6. This Space Network constellation of four active TDRS's, which could provide eight high-rate transmission channels at a time, is the basis of our current long range plan which was prepared in August 1986.

We will continue to perform mission model analyses to assess the support capacity of the NASA Space Network and properly update our planning to assure continued Space Network responsiveness to our user community.

COMPUTER SCIENCE PROGRAM

See comment 7. Page 10, last paragraph - It is suggested that the report note: (1) the establishment of a modest computer science program at NASA in 1982 to perform collaborative research with the university community and build in-house computer science expertise, and (2) that the automation and robotics program has grown progressively in 1985, 1986, and 1987, with additional growth proposed in 1988.

See comment 8.

NASA

National Aeronautics and Space Administration

Washington, D.C. 20546

Office of the Administrator

Enclosure 2

DEC 10 1985

Honorable Edward P. Boland
Chairman
Subcommittee on HUD-
Independent Agencies
Committee on Appropriations
House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

As you know, the Congress directed, in Public Law 98-371, that NASA establish an Advanced Technology Advisory Committee (ATAC), in conjunction with the Space Station program, to identify specific Space Station systems which advance automation and robotics (A&R) technologies. The initial recommendations of the ATAC were transmitted to the Congress in March 1985. A further requirement of P.L. 98-371 is that the ATAC follow NASA's progress in automation and robotics for the Space Station, and report to Congress semiannually. Transmitted herewith is the third progress report of the ATAC.

This report acknowledges that "major progress has been made in the definition and preliminary design of applications and technologies for automation and robotics on the Space Station," and that "substantial progress has been made in the development of a U.S. telerobotic capability for the initial Space Station." However, at the same time, the report outlines a series of shortcomings in NASA's current efforts. I intend to have these matters addressed, and the Associate Administrator for Space Station, Mr. Andrew J. Stofan, has already undertaken significant steps toward this end. A synopsis of the current ATAC progress report is presented below, followed by descriptions of the corrective measures taken by the Space Station program.

See comment 9.

- Major progress in definition and preliminary design of applications and technology for Space Station A&R is sufficient to merit extensive inclusion of A&R in the initial operating capability and growth Stations. NASA agrees that significant work has been accomplished, and intends to capitalize on it through Phase C/D and beyond. The potential enhancement resulting from the use of A&R has also been stated by the Critical Evaluation Task Force in its redefinition of the Program. No firm conclusions have been reached, however, on the appropriate level or timing of A&R capabilities.

See comment 9.

- Planning for operations and system autonomy is not progressing quickly enough to influence design, and the benefit in life cycle costs offered by advanced automation is not being appreciated or balanced against initial cost. NASA acknowledges that, to date, the emphasis on an architectural approach to satisfy a diverse set of users has been far greater than on operations. However, program planning is now entering a phase in which the deficiencies cited by ATAC should be overcome.

  In mid September, the Operations Task Force (OTF) was organized and chartered to study Space Station operations and to provide timely recommendations for the Phase C/D RFP. We scheduled intensive briefings for the OTF on A&R applications and opportunities and expect them to formulate an operations concept that includes consideration of A&R and initial costs in evaluating design tradeoffs.

See comment 10.

- A&R considerations must be given high priority in the Phase C/D procurement process. NASA fully concurs with this finding, and the Program is developing the Phase C/D RFP documents in a manner which explains the position which NASA wishes to take with regard to A&R (including design knowledge capture). A requirement is imposed that all RFPs contain equally explicit language on the value of A&R to the program and importance of the various benefits expected from A&R applications. We will also include in the evaluation criteria section of the RFP precise guidance regarding the importance of the quality and quantity of A&R applications.

See comment 11.

- NASA is perceived as not committed to the inclusion of A&R recommendations in the Program. NASA believes that such a perception is a consequence of the predominant focus to date upon the Space Station architecture. However, a series of steps have been undertaken by the Program to correct this perception:

See comment 11.

  - -- the appointment of a Division Director at Level A with direct responsibility for A&R, and a planned organizational element at Level A', reporting directly to the Program Director, responsible for A&R coordination across work packages and for program-wide tradeoffs;

  - -- enhanced programmatic capability in system analysis, engineering and integration through the establishment of the Level A' organization and pending selection of a strong supporting contractor; such a capability will enable performance of trade-offs and examination of options which will result in an optimal plan for A&R applications;

See comment 12.

  - -- appointment of an A&R advocate to the procurement working group supporting the coordination of the Phase C/D RFPs; and,

  - -- the establishment of the Operations Task Force;

- Use of the Space Station Flight Telerobotic System (FTS) has not been planned. As of the date of the printing of the ATAC progress report, only a preliminary plan for the FTS was in place. However, since receiving the responsibility for development of the FTS in May 1986, the Goddard Space Flight Center has been assembling a strong team and developing a detailed program plan. A preliminary set of requirements has been formulated, and final requirements, suitable for inclusion in an RFP, are expected in January 1987. The FTS RFP will be a separate procurement from the balance of Work Package 3, in an effort to incorporate the widest range of the most advanced technologies. Furthermore, recognizing the principal uses of the FTS, NASA has formulated two teams focusing upon assembly/maintenance and servicing, at the Johnson Space Center and Goddard Space Flight Center, respectively. These teams are examining the systems aspects of those functions, and formulating "architectures" for their performance using the capabilities available through both the FTS and extra-vehicular activity.

I believe the foregoing demonstrates that the Program is taking heed of the constructive advice offered by the ATAC, and is thereby increasing the Program strength in the important field of automation and robotics.

In closing, I would like to take this opportunity to note that with my recent appointment of Mr. Aaron Cohen as Director of the Johnson Space Center, the ATAC has lost a most effective Chairman and enthusiastic A&R advocate. I have appointed Mr. Robert A. Nunamaker, Director for Space at the Langley Research Center, and a charter member of the ATAC, to succeed Mr. Cohen as ATAC Chairman, to insure a continuity of outstanding leadership.

Sincerely,

James C. Fletcher
Administrator

Enclosure

GAO Comments

1. As described on page 1, our report is intended to be an overview of information technology critical to NASA's space missions. It is not intended to be a comprehensive survey of all space-related information technology projects being pursued by the agency. We note on numerous pages of our report that NASA has modernization projects under way in several information technology areas, including ground systems. We did not believe it was appropriate for this overview to include detailed descriptions of every information technology project. However, all the projects mentioned by the agency in its comments were considered in our review.

2. We state on page 45 of our report that a NASA official told us that two agency telecommunications systems, one called NASCOM and the other called the Program Support Communications Network, were close to being overloaded. NASA, in its comments, made a general statement that appropriate plans are being made to upgrade the two systems, but provided no specifics. As recently as March 1987, the NASA program manager in the Office of Space Science and Applications told us that the performance of these two principal systems had degraded. He also stated that he was not aware of any immediate plans to increase the systems' capacity. Without more specific information, we are unable to address NASA's plans in this area.

3. Our reference to standard magnetic tape, which holds 6,250 bits of data per inch, is included to give the reader an idea of the magnitude of data being discussed. The text, on page 49 of the report, explicitly states that no one has proposed using magnetic tape to store the scientific data being discussed.

4. The phrase "space network" has been revised using NASA's phrase "baseline space network." Because the agency may add two additional satellites later, the term "baseline" was used to distinguish between the initial two-satellite operational network and NASA's plans for future expansion of the network.

5. The paragraph in the draft report that this sentence was taken from has been revised to recognize that NASA has a long-range plan to deploy two additional satellites. Our previous statement that NASA was no longer "actively pursuing" plans to deploy the two additional satellites stemmed from our review of NASA documents and discussions with NASA officials. Both sources indicated that the space network configuration considered for the early to mid-1990s included two active and one spare telecommunications satellites. Further, the agency's approved manifest for shuttle flights planned through 1994 verified this configuration. Specifically, the manifest did not show plans to launch the two additional satellites that the agency had included in its 1986 long-range plan for the space network.

6. NASA's long-range plan for the space network proposes a configuration of four active satellites. However, to meet this goal, the agency has to add two dedicated shuttle flights to its schedule and ensure that five satellites are placed in orbit without degraded capabilities. Given these uncertainties, we believe the question of what specific actions NASA is taking to ensure the adequacy of its space-based telecommunications systems remains one that the agency and the House Committee on Science, Space, and Technology may wish to consider.

7. The report has been changed to reflect progressive funding growth from fiscal years 1985 through 1987, with additional funding requested for fiscal year 1988. However, we have not yet assessed the proposed funding levels to determine if they are adequate to ensure that the quantity and quality of automation and robotics technologies will be available for Space Station use when needed.

8. This letter was used by NASA to transmit copies of the Advanced Technology Advisory Committee's October 1986 report on automation and robotics to the Subcommittee on HUD-Independent Agencies, House Committee on Appropriations. NASA provided this letter, for our consideration, when it commented on our draft report. We had used information from this letter when we prepared our draft report. The following comments, numbered 9 through 12, explain how this was done.

9. This represents a general statement by NASA about the Advanced Technology Advisory Committee's October 1986 progress report, including planned actions that the agency intended to take regarding the Committee's concerns. Because the result of these actions cannot be assessed until the agency issues its final requests for proposals for the detailed design and development phase contracts, we have not addressed these planned actions in our report. We do mention on page 38 that the agency has reached no firm conclusions on the appropriate level of timing of automation and robotics capabilities for the Space Station.

10. As discussed on page 38, we did make a preliminary analysis of the draft requests for proposals for the detailed design and development phase contracts to determine if NASA had addressed the Advanced Technology Advisory Committee's concerns. Because these proposals were not final at the time we completed our work, we did not determine if they had been appropriately modified.

11. We mention on page 38 that NASA has appointed a Division Director in the Office of Space Station to give automation a more significant role in Space Station design.

12. NASA is referring to the Advanced Technology Advisory Committee's concern about the agency's progress in developing plans for using the flight telerobotic servicer on the Space Station. Regarding the overall use of robotics on the station, which would include the flight telerobotic servicer, we mention on page 37 that overall, the committee found that NASA's planned use of robotics on the Space Station looked promising.

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FOOTNOTES

[1] For purposes of this review, we have defined information technology as computers (hardware and software), sensors, robotics, and telecommunications systems that NASA uses to support its mission.

[2] "Mission Operations Directorate: Flight Rate Capability Study," Johnson Space Center, September 1986.

[3] Public Law 98-371 (98 Stat. 1227), July18, 1984.

[4] Advanced automation and robotics can be defined as the use of machines, either computers or robots or both, to perform pre-designated tasks largely without human intervention.

[5] "Advancing Automation and Robotics Technology for the Space Station and for the U.S. Economy," NASA-TM87566, March 1985.

[6] "Advancing Automation and Robotics Technology for the Space Station and for the U.S. Economy—Progress Report 3," NASA-TM89190, October 1986.

[7] "Advanced Automation for Space Missions," University of Santa Clara, Santa Clara, CA, September 1980.

[8] "Automation and Robotics for the Space Station: Phase B Considerations, An OTA Staff Paper," 1985.

[9] Letter dated December 10, 1986, from NASA's Administrator to the Honorable Edward P. Boland, Chairman, Subcommittee on HUD and Independent Agencies, House Committee on Appropriations. This letter is included in our report as enclosure 2 of appendix VII.

[10] Real-time applications control an ongoing process and deliver outputs or inputs not later than the time when these are needed for effective control.

[11] This includes flight number 51L, the *Challenger*, that was lost after launch in 1986.

[12] "Flight Rate Capability Study," Mission Operations Directorate, Johnson Space Center, September 1986.

[13] "Guidance on Software Maintenance," National Bureau of Standards Special Publication 500-106, December 1983.

[14] "The Obsolescence of National Airspace System Software," MITRE Corp., WP 81W00412, August 1981.

[15] "Expert Systems Handbook," Mission Support Directorate, Mission Planning and Analysis Division, NASA, July 1986.

[16] For purposes of this report, advanced automation means the use of yet emerging technologies for space, including artificial intelligence, teleoperation, and robotics.

[17] The technology and devices for carrying out, under human or automatic control, physical tasks that would otherwise require human abilities.

[18] "NASA's Automation and Robotics Technology Development Program: A White Paper, March 1986.

[19] Systems capable of performing independent operations.

[20] The execution of tasks by a robot controlled by a human operated manipulating device.

[21] A committee required to be established by NASA pursuant to Public Law 98-371 (July 18, 1984) to identify specific Space Station systems which advance automation and robotics technologies not in use in existing spacecraft.

[22] "Automation and Robotics for the Space Station: Phase B Considerations, An OTA Staff Paper," 1985.

[23] "Advancing Automation and Robotics Technology for the Space Station and for the U.S. Economy," NASA-TM87566, March 1985.

[24] "Advancing Automation and Robotics Technology for the Space Station and for the U.S. Economy," NASA-TM89190, October 1986.

[25] "Manual for Preliminary Design of Space Station Machine Intelligence, Robotics, and Automation, Office of Space Station, NASA, July 1986.

[26] "Data Management and Computation, Volume 1: Issues and Recommendations," Committee on Data Management and Computation; National Research Council, National Academy Press, 1982.

[27] "Issues and Recommendations Associated With Distributed Computation and Data Management Systems for the Space Sciences, Committee on Data Management and Computation; National Research Council, National Academy Press, 1986.

[28] "LZP: Level Zero Processing in the Space Station ERA," with MITRE Corp., WP-26830, July 10, 1986.

GAO COST ESTIMATES

Senator PROXMIRE. Do you have any estimate of how much it would cost to bring NASA up to speed?

Mr. PALMER. The committee that has studied this has estimated that they should be spending on the order of $190 million a year by 1990 given the previous schedules of development. What we noted was that over the current 3 fiscal years that would call for on the order of over $300 million of expenditures. Their current planned rate is like $53 million.

The total estimated for the entire program, when given those differences in estimates, I really don't have a good one for you.

Senator PROXMIRE. If I understand, you said that your estimate is that it would cost $300 million a year; is that right?

Mr. PALMER. No.

Senator PROXMIRE. $300 million over 3 years, I beg your pardon.

Mr. PALMER. Their estimate called for about $300 million over the next 3 fiscal years, but the planned rate of expenditure is around $53 million, which is far short of that committee's goal.

Senator PROXMIRE. Over 3 years?

Mr. PALMER. Yes; $53 million in total over the 3 years.

Senator PROXMIRE. So they would have to increase the expenditures by sixfold?

Mr. PALMER. Yes, sir.

COSTS ASSOCIATED WITH INFORMATION TECHNOLOGY

Senator PROXMIRE. If NASA doesn't show real progress in incorporating new automation and information technology opportunities in transportation systems, what kind of cost and operational constraints will arise in terms of dollars and months of delay?

Mr. PALMER. Sir, you said "transportation systems," and I just want to clarify what you mean, the station or the shuttle transportation system?

Senator PROXMIRE. Both.

Mr. PALMER. From what we have studied, NASA has been forging ahead with the plans for the detailed design and physical development. The development of the advanced information technology needed for the station may actually mean additional expense and delay in building the initial station if it intensifies its efforts to fully develop and demonstrate that advanced technology before it puts it in.

If they don't, the overall life cycle costs could be significantly higher. Based on our work, and the work done by the Advanced Technology Advisory Committee, it is quite possible that if NASA does not now lay the proper foundation for the incorporation of this technology in the initial station, the later incorporation of this technology could be prohibitively expensive, and the life cycle costs would then continue to be higher than they need to be. Unfortunately, we have not seen good studies that would quantify the benefits and risks of including it now or later.

In terms of the shuttle, I would like my colleague, Douglas Cannon, to answer that, because he studied the shuttle transportation system a little more.

Senator PROXMIRE. Go right ahead, sir.

Mr. CANNON. I think a good example of this issue is the information systems technology that is used in the existing shuttle operations. That information system's architecture is based in large part on that from the Gemini and Apollo projects and, consequently, does not have to date high levels of automation in it.

Also because of the growing obsolescence of that technology, it is not clear how much automation can actually be retrofitted back into that architecture. According to NASA officials, this technological and architectural obsolescence could limit the number and complexity of missions flown, increase the operational cost of those missions, or both of those effects.

MAN-TENDED APPROACH

Senator PROXMIRE. Let me ask you this question. What would be the pros and cons of using a man-tended station between now and 1995, the interregnum, going to the permanent station after a man-tended station had satisfied immediate science needs and provided for information technology development time?

Mr. CANNON. We are not fully prepared on that question, sir. The man-tended approach is kind of a recent change, and neither we, nor what I have seen from NASA, has really considered the full effects of what automation would make on that.

Some pros and cons do come to my mind. It is that the man-tended approach should provide time to gain actual experience with certain on orbit and ground operations necessary to support that type of experimentation, and that should help NASA to determine what should be automated, and the technology and the technical risks and objectives for accomplishing that level of automation.

Indeed, our work on the automation programs at FAA and in the military circles indicates that mature operating experience is very important to doing advanced technology. On the other hand, by not having a crew on board to do certain daily planning and housekeeping functions could mean more extensive ground support operations, and that implies higher operational costs on the ground.

Also this approach places added burden on NASA to design sufficient flexibility into the on-board data system so that they can accommodate automated functions later.

DATA RELAY NETWORK

Senator PROXMIRE. In your report, you indicate the need for an expanded data relay network in space. Specifically, you say two more satellites will be needed. Without this expanded capability, NASA would be strapped to capture and handle all the data which would come in from its manned and unmanned units.

You indicate that there is no evidence that this network expansion will occur. If it does not, will this limit the value of a space station; that is, would we have a space station, but no place to send the data?

Mr. PALMER. What we report, sir, is primarily from what the NASA studies. We have not come to a conclusion on that matter. We simply want to point out to the Congress that as a concern, what they are capable of doing with the existing two satellites relative to what they plan to do with all of the other programs in space, you have a limitation of the data communication's capability. Significant amounts of data could be lost.

The vehicle that it was lost from would depend on several factors. If there were limitations on the amount of data that could be handled by the existing two TEDRA's, I believe NASA would be forced to decide not only which vehicle—for example, the space station or another lower orbiting satellite—it communicated with, and the type of data process—for instance, whether it is scientific or payload data versus its housekeeping or critical operational telemetry. It would have to be chosen between if you don't have enough capacity up there.

If NASA chose to process all data from the space station, both scientific and its operational telemetry, then data could be lost from other vehicles considered important, such as the Hubble space telescope, or the planned Earth observing system. The amount of data lost would depend on each vehicle's capability to store data internally, and then forward it when data communications capability became available.

Unfortunately, most of the current lower Earth orbiting vehicles have insufficient capabilities to store large amounts of data. They also lack a very high data transmission capability to send it quickly through the system.

Senator PROXMIRE. You are confirming again the analogy of the house without furniture.

Mr. PALMER. Yes, sir.

Senator PROXMIRE. In this case the furniture or the electrical system. In the old days it wouldn't have mattered so much, but today you couldn't watch television.

Mr. PALMER. The ground support in the sense of foundation is probably even more analogous.

Senator PROXMIRE. A house without a foundation?

Mr. PALMER. Certainly a couple of pillars.

Senator PROXMIRE. A couple of pillows or pillars?

Mr. PALMER. Pillars.

Senator PROXMIRE. That is not much of a house. This was a very helpful response.

Mr. PALMER. From what we looked at, sir, there was also a concern about the capabilities of the ground communications systems as well to handle all of this data as it came down, and move it around to the various places that were to process it.

ADDITIONAL SATELLITES

Senator PROXMIRE. You indicate that the two more satellites that would be needed, there is no indication that that is going to occur; is that right?

Mr. PALMER. In the budget, they are not scheduled. In the planned manifest that we have seen of late, there is a statement from NASA in response to our report that they have a long-range plan to provide two more satellites. It is simply not evident in what we see in concrete plans for the next several years.

Senator PROXMIRE. We have a station, but no place to send the data.

Mr. PALMER. Very limited capability; yes, sir.

Senator PROXMIRE. What would it cost in order to rectify that, to have the two satellites, and so forth?

Mr. PALMER. As I said, the only thing we have from NASA is a long-range statement that they will, and not an estimate of what they would cost.

Senator PROXMIRE. What is your estimate?

Mr. PALMER. We don't have one, sir, I am sorry.

Senator PROXMIRE. Would it be possible for you to develop estimates?

Mr. PALMER. I think so.

Senator PROXMIRE. How long would it take?

Mr. PALMER. A matter of weeks.

Senator PROXMIRE. I think that it would be very helpful for the Congress to have that so we know where we are going. This is a very substantial commitment that we have to make, and this is very important to the subcommittee. I hope that you will be able to develop that in the next few weeks.

Mr. PALMER. We will be happy to do so.

Senator PROXMIRE. Very good.

Thank you, sir, very much.

SUBCOMMITTEE RECESS

The subcommittee will stand in recess until next Friday, May 8, at 10 a.m., in room SD–124, when we will take testimony from public and congressional witnesses on the proposed budget for the agencies under this subcommittee.

[Whereupon, at 12:35 p.m., Friday, May 1, the subcommittee was recessed to reconvene at 10 a.m., Friday, May 8.]

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION SPACE STATION PROPOSAL

TUESDAY, MAY 20, 1987

U.S. SENATE,
SUBCOMMITTEE OF THE COMMITTEE ON APPROPRIATIONS,
Washington, DC.

The subcommittee met at 10:08 a.m. in room SD–138, Dirksen Senate Office Building, Hon. William Proxmire (chairman) presiding.

Present: Senators Proxmire, Garn, and Grassley.

NONDEPARTMENTAL WITNESSES

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OPENING STATEMENT OF SENATOR PROXMIRE

Senator PROXMIRE. The subcommittee will come to order.

Today we will take testimony from seven witnesses on the proposed space station. It is the subcommittee's intention to give particular attention to the commercial value of the station as presently configured as well as the feasibility and practicality of a more incremental approach.

In my estimation, we face a fundamental difficulty in discussing the station as it is presently conceived by the National Aeronautics and Space Administration.

On the one hand, the station is being sold, and I quote, "As an orbiting laboratory for the conduct of science, the development of new technologies, and the stimulation of commercial enterprises." Those words are from NASA Administrator Fletcher's testimony to this subcommittee.

On the other hand, when we hear from eminent scientists who question the value of the station, we are told that you can always find some scientists who are critical of anything. If we ask about industrial involvement outside the aerospace sector, we are told that it is foolish to expect industry to take part at this early stage.

BLIND LEAP OF FAITH

It would seem that we are supposed to believe that if we invest $20 or $30 billion in a space station, it is bound to be productive; will it? Consider this statement, and then listen to the source.

I quote:

The present space station program is nothing more than a olind leap of faith. If we take this leap, almost nothing will get done at NASA, our only agency for doing civilian space projects. An exclusive commitment to the space station would be even more tragic than our exclusive commitment to the space shuttle.

Those remarks were not made by a penny-pinching Senator or an academic researcher from his ivory tower. They were made by Albert Wheelon, chairman of the board and chief executive officer of the Hughes Aircraft Co., a concern some of today's witnesses may be familiar with. We had hoped to be able to hear from representatives of a number of nonaerospace industries today, but the only nonaerospace witness we will hear from is Louis Lanzerotti of Bell Labs.

We were particularly interested in taking testimony from the Ortho Pharmaceutical subsidiary of Johnson & Johnson because of the firm's involvement in a joint venture to produce pharmaceuticals in space and their subsequent withdrawal from the endeavor.

CORRESPONDENCE

The staff has discussed this issue with Dr. Kiplinger of Ortho and we have received a letter indicating that advances in biotechnology made this approach less promising. The letter will be included in the hearing record.

[The letter follows:]

LETTER FROM GLENN F. KIPLINGER, VICE PRESIDENT, RESEARCH AND DEVELOPMENT, ORTHO PHARMACEUTICAL CORP.

MAY 15, 1987

SENATOR WILLIAM PROXMIRE
HUD AND INDEPENDENT AGENCIES SUBCOMMITTEE
SENATE APPROPRIATIONS COMMITTEE
WASHINGTON, D. C. 20510

DEAR SENATOR PROXMIRE:

MR. VAN DERVOORT HAS ASKED ME TO DISCUSS ORTHO PHARMACEUTICAL CORPORATION'S INVOLVEMENT WITH MC DONNELL DOUGLAS AND THE NASA PROGRAM ON THE POTENTIAL COMMERCIALIZATION OF SPACE APPLICATIONS.

ORTHO AND MC DONNELL DOUGLAS ASTRONAUTICS COMPANY (MDAC), A DIVISION OF MC DONNELL DOUGLAS CORPORATION (MDC) ENTERED INTO A JOINT ENDEAVOR AGREEMENT IN 1979. THE BASIC PRINCIPLES OF THAT AGREEMENT WERE TO COLLABORATE ON THE RESEARCH AND DEVELOPMENT OF A PHARMACEUTICAL PRODUCT UTILIZING A NEW TECHNOLOGY FOR PROCESSING IN A MICROGRAVITY ENVIRONMENT DEVELOPED BY MDAC. IN 1983, THAT AGREEMENT WAS FURTHER SOLIDIFIED BASED ON ADVANCES MADE BY MDAC IN CONTINUOUS FLOW ELECTROPHORESIS AND ON THE JOINT IDENTIFICATION OF A SPECIFIC PRODUCT, ERYTHROPOIETIN.

CONTINUOUS FLOW ELECTROPHORESIS IS A METHOD OF SEPARATION OF LARGE MOLECULES, SUCH AS PROTEINS, BASED ON THEIR MOVEMENT IN A BUFFER FLUID FLOWING THROUGH A LOW VOLTAGE ELECTRICAL FIELD. THE PROCESS ON EARTH IS LIMITED BY GRAVITATIONAL EFFECTS, SINCE THE PROTEIN MUST BE IN A DILUTE SOLUTION IN ORDER TO AVOID DIFFERENCES IN DENSITY BETWEEN THE BUFFER FLUID AND THE PROTEIN SOLUTION. BY OPERATING IN A MICROGRAVITY ENVIRONMENT THE EFFECTS OF DENSITY GRADIENTS ARE REMOVED AND THE EFFICIENCY OF SEPARATION CAN BE INCREASED BY SEVERAL HUNDRED FOLD. THE THEORETICAL AND PRACTICAL WORK DONE BY MDAC IN THIS AREA WAS TRULY A SCIENTIFIC ADVANCE IN SEPARATION TECHNOLOGY.

WHILE THE ENGINEERING OF A DEVICE TO FIT THE REQUIREMENTS OF SPACE FLIGHT WAS PROGRESSING, ORTHO AND MDAC DISCUSSED IN DEPTH SPECIFIC PROJECTS OF MEDICAL INTEREST WHICH WOULD BE AMENABLE TO THIS KIND OF TECHNOLOGY AND SELECTED ERYTHROPOIETIN, A PROTEIN HORMONE PRODUCED BY THE HUMAN KIDNEY AND SECRETED INTO THE BLOOD STREAM. ERYTHROPOIETIN ACTS ON THE PRECURSORS OF RED BLOOD CELLS LOCATED IN THE BONE MARROW. A LACK OF ERYTHROPOIETIN, AS OCCURS

IN KIDNEY FAILURE, RESULTS IN ANEMIA. THE HORMONE HAD BEEN AT THAT TIME AVAILABLE IN ONLY TRACE QUANTITIES. SMALL ANIMAL STUDIES HAD DEMONSTRATED THE POTENTIAL BENEFIT OF THE COMPOUND, BUT AVAILABLE QUANTITIES HAD PREVENTED ANY HUMAN EXPERIMENTATION.

WE RECOGNIZED IN OUR EARLY DISCUSSIONS THAT A MAJOR COMPETING TECHNOLOGY WHICH MADE PRODUCTION, SEPARATION, AND PURIFICATION FEASIBLE IN AN EARTH BASED SYSTEM, COULD RENDER THE MICROGRAVITY PRODUCTION SYSTEM ECONOMICALLY UNSOUND. IN FACT, DURING THE APPROXIMATELY 6 YEARS OF THE AGREEMENT, ENDING IN 1985, THAT HAPPENED. THE TECHNOLOGIES FOR IDENTIFYING PROTEIN STRUCTURE, FOR CREATING THE GENETIC INFORMATION NECESSARY TO CREATE THAT PROTEIN, AND THE TECHNIQUES OF CELL CULTURE ADVANCED SO RAPIDLY THAT ERYTHROPOIETIN COULD BE PRODUCED IN GROUND BASED EQUIPMENT.

THE DECISION TO STOP WORK ON THE ELECTROPHORETIC SEPARATION WAS PURELY AN ECONOMIC DECISION BASED ON ADVANCES IN OTHER TECHNOLOGY WHICH HAD OCCURRED IN THE INTERVENING YEARS.

THE PROCESS KNOWN AS EOS (ELECTROPHORESIS OPERATION IN SPACE) STILL REPRESENTS A HIGHLY SOPHISTICATED TECHNOLOGY FOR PROTEIN SEPARATION. I CANNOT CITE SPECIFIC EXAMPLES, BUT I BELIEVE THAT THERE ARE SITUATIONS IN WHICH IT WOULD BE HIGHLY DESIRABLE TO SEPARATE SMALL, HIGHLY PURIFIED SAMPLES OF NATURALLY OCCURRING SUBSTANCES IN ORDER TO IDENTIFY STRUCTURE AND OTHER PHYSICAL CHEMICAL CHARACTERISTICS. IN SHORT, I BELIEVE MDAC IS TO BE COMMENDED FOR THE EFFORT WHICH WENT INTO EOS AND FOR THE FUNCTIONING DEVICE THEY HAVE DEVELOPED. I BELIEVE IT MAY STILL FIND UTILITY, EVEN IF IT IS NOT THE SPECIFIC UTILITY ENVISIONED IN 1979.

I SINCERELY HOPE THAT THIS INFORMATION IS USEFUL TO THE CONSIDERATION OF YOUR SUBCOMMITTEE.

SINCERELY,

Glenn F. Kiplinger

GLENN F. KIPLINGER

ORDER OF TESTIMONY

Senator PROXMIRE. In any event, we will take testimony first from Oliver Harwood, an aerospace engineer of some note, who has proposed an innovative modular alternative to the current space station design. Mr. Harwood will be paired with Ray Hook of NASA who can discuss the agency's response to this suggested approach.

We will then take testimony from a five-man panel composed of Charles Walker of McDonnell Douglas, George Merrick of Rockwell International, Louis Lanzerotti of Bell Labs, Jerry Grey representing the American Institute of Aeronautics and Astronautics, and L.J. Evans, Jr., of the Center for Space and Advanced Technology.

I hope all of these gentlemen can shed some light on the use of the station to "stimulate commercial enterprises," to quote Dr. Fletcher. I am going to ask each witness to limit his prepared remarks to 10 minutes and we will then ask questions in the aforementioned panel framework.

I am delighted to see that Senator Garn has arrived, and I am happy to yield to my good friend.

REMARKS OF SENATOR GARN

Senator GARN. Thank you very much, Mr. Chairman. I will be brief, simply welcome our witnesses this morning, and I have to especially welcome Charlie Walker.

If you are not aware of this, or the other people are not, Charlie and I flew together. He had to put up with me on the middeck of *Discovery*, and I mean so close, sitting together, that his right elbow was in my ribs on the left side.

So, he is a very close personal friend. You don't spend 7 days in space with another human being without becoming very close to them, having that type of an experience.

So, all of the witnesses are very distinguished, but I am particularly pleased that Charlie is here, and one of the few people that has flown three times. I am very jealous of him.

I got to fly with him on his second flight, but he had flown before and he flew again. So, I hope my jealousy doesn't show too much that he has had the opportunity to fly three times aboard the space shuttle.

Thank you, Mr. Chairman.

Senator PROXMIRE. Thank you, Senator Garn.

Mr. Harwood, we are delighted to have you as our first witness. Why don't you and Mr. Hooks come to the witness table and you can proceed with your testimony.

STATEMENT OF OLIVER P. HARWOOD, STRUCTURAL, MECHANICAL, AND CONFIGURATION DESIGNER

Mr. HARWOOD. This is my prepared statement. I am here on behalf of other engineers, mostly anonymous, employed, like myself, in the aerospace industry.

My interest is evident to anyone who might read my article entitled, "An Evolutionary Space Station Architecture." An article which was published in the Journal of the British Interplanetary Society, the July 1985 issue, and recently brought to public attention in the Los Angeles Times.

I will state my case as succinctly as possible, although I don't get this kind of opportunity that often, and I will probably be fairly blunt.

AEROSPACE BACKGROUND

My credentials are that I am a 64-year-old structural, mechanical, and configuration designer with 43-plus years in aerospace.

I was the originator of the grid construction in Skylab, a design intended for physical integration of the subsystems in that program, a design whose performance, in many respects, exceeded original intentions, because it was adaptable.

I hold three mechanical patents. I am the author of three articles on space system design, published in the Journal of the British Interplanetary Society, one of them the space station article previously mentioned, and another a dissertation on the equally timely subject of safe access to habitable pressurized spaces. That was in the August 1986 issue.

My position in this general subject of space station to begin with is that space station is a worthwhile enterprise which should be pursued.

POOR DESIGN OF SPACE STATION

My second position is that NASA's plans for space station are wrong; the design is bad. For these reasons, inadequate growth and shrinkage causes too much up-front cost. The system is unadaptable. There are too many adapters; nothing fits.

The system is configuration constrained. A growth station's configuration would be long forgotten after 20 years, so configuration is the wrong issue; it is the construction system that counts, one which can make any configuration. I feel that NASA has failed to recognize that space station is a process, not an event.

HARWOOD DESIGN

My next point: the system described in my article offers the desired growth and adaptability, would be simpler to develop, only six main elements, and could be operational after four launches with a starting capability roughly equivalent to Skylab.

An estimated 50-percent cost reduction is attainable, especially at the funding peaks. An eventual 100-fold or more growth is foreseen, so funding can be steady and incremental over the life of the program, a life of at least 20 years and quite easily more.

COMPETITIVE SOLUTIONS NEEDED

My second point is that aerospace industry resources and capabilities are being squandered by rubber stamping NASA designs instead of seeking independent and competitive solutions to system problems.

Why are the artist's conceptions of eight major corporations so nearly identical? In a real competition seeking real answers, there would be as there has been in the past, a different version for each of them.

The eight I am referring to are Lockheed, McDonnell Douglas, Rockwell, General Dynamics, Grumman, Boeing, Martin Marietta, and TRW. If there are any I have omitted, I apologize to them. Surely someone must be thinking and unable to get his ideas out.

My next point is a somewhat parenthetical remark about the climate we are in. When NASA was in its infancy in the early 1960's, it possessed some of the residual arrogance of the bureaucracies from which it was formed, with considerable augmentation from the billions of dollars of public funds entrusted to its care.

However, generally lacking experience in design and development of hardware, it allowed industry to handle these tasks, reserving for itself the right to review and criticize. In this mode of operation there was a balance and the damage from the agency's interference was minimized.

However, he who holds the gold makes the rules and the situation today is quite different. A friend of mine working on the space station program identified a problem and suggested a possible solution, only to be told by his supervisor, "On this program we don't solve problems, we evaluate NASA's solutions to problems."

The objectivity of such evaluations must be left to the imagination. One can also imagine how much real industry participation the U.S. public has received for its money. It is not hard to understand why American competitiveness and the alleged American technological lead in space are in deep trouble.

PROPOSED RECOMMENDATION

My next point is a recommendation. The present course should be stopped. There is no point in being on schedule when there is a washed out bridge up the line. Since in spite of time and expenditure there has been no real phase B study, four or five such studies should now be awarded, throwing out restrictive ground rules and eventually narrowing the field to two or three phase C/D finalists.

Any one of these competitors should be able unfettered to accomplish more in 6 months than has been done in the past 2 years. Nobody is ready for hardware yet. Let the final winner be the prime contractor.

My contention is that even at this late date, time would be saved by some such move. The procurement and management plan is a disaster and a major contributor to the poor quality of the design. This means that the requests for the aforementioned proposals should emanate from headquarters with center responsibility assigned after the development plans are sorted out.

The Banks Committee recommendation for space station redesign was the right idea, even if the alternatives suggested were not. As a NASA official stated in response, "How can NASA admit that after 15 years and $600 million they don't know what a space station is?" Apparently someone, maybe Congress, has to say it for them.

INVOLVEMENT IN SPACE PROGRAM

My involvement in the program has been like this: In mid-1983 I had a pre-phase B advance design assignment to develop modules for shuttle, which could evolve into an embryo space station. This was a NASA JSC backdoor approach in the absence of funding.

That was followed by a review of a decade of inadequate study results and wheel spinning. Mainly, the configurations lacked growth and were not very sound structurally.

This was followed by the discovery of the need for a space lattice system to anticipate unforeseen and unforeseeable future needs, choices narrowing rapidly to the tetrahedral form, which is the only triangulated system made from elements of the same length, which is stable. That means it is constructible with toothpicks.

This is followed by the discovery of the appropriate hub geometry for such a thing and the indexing and orientation which can be defined unambiguously for its construction.

In early 1984, I got to the definition of the six basic elements, five if all the hab modules are the same size. I made eight internal presentations at my employer's shop to advanced designs to the newly appointed space station program chief engineer, to the directors, the division president, proposal team and the requirements group.

There was generally favorable reception, no feasibility flaws identified, and people asking, why not? The result of this was no evaluation or support, no mention in the proposal, no referral to NASA, and no further participation in the program on my part.

CONSTRUCTIVE CRITICISM PUBLISHED

So, not to waste the effort, after waiting a period of several months, I put the material together and submitted it to the British Interplanetary Society with a subsequent publication. That was in July 1985.

The article was sent to Senator Glenn, who forwarded it to NASA JSC. The NASA "evaluation" said in effect, "Don't bother me, my mind is made up." It was a very frivolous response to say the least, and some of you have seen it.

My rationale for doing this was as follows: The JBIS article was intended to be constructive criticism, offering a better alternative without carping about or identifying the shortcomings of the official plan.

It produced no results. I think there is a statement that, "It takes a 2-by-4 to get a mule's attention" or something like that, but you have to get serious on things like this.

The idea was that if a United States start is 8 years behind the Soviets, that start should be as advanced and advanceable as so-called Yankee ingenuity could devise.

This "me too" which seems to be happening these days is not good enough. The concept was to begin extension of the growth and adaptability features initiated on Skylab, but benefiting from subsequent experience and new opportunities. The current effort has pieces that don't even fit.

PRESENT DESIGN INADEQUATE

This is not representative completely of existing configurations. The problem with this is that the elements that make up the station are construction bars, nodes at their intersections, nodes that are pressurized adjoining habitable modules. If you will notice, three box truss bays are slightly longer than four node widths. It is not going to fit there, and the hab module is slightly less than that.

The point is that the problem with the present design are simple things. It simply doesn't fit. That makes growth difficult because every situation demands adaptors.

You can see them hinted at on the right side of the chart there. As they pile up, every time you add more there is a completely unique situation so a new adapter has to be devised and more rework to the structure of this up there, which is very difficult to do at that point.

In contrast, what I have been trying to get across—this is a two-dimensional representation, this is a three-dimensional one. There are six elements, as you see.

The distance center to center between nodes, which are a tetrahedral lattice whose points can fill in all those spaces if we had the time and budget. Those gaps are filled in the different ways shown there.

One habitable module which consists of two cylindrical pieces and an end-cone is joined to a pressurized node to make one payload bay worth. The habitable module is made of the two kinds, so that it also can be made in different lengths and these lengths are multiples of the length of a node, so that they can be interchangeably inserted, in one instance, showing two nodes together. The reason for having that many nodes is that each has 12 ports, part of which are occupied with the construction and all the rest of which are for plugging in experiments.

The rule of construction for such a system would be that all experiments are attached at a standard interface which is on the node and that is the only place you do it.

There are quite a lot of opportunities because of all the different directions you get into in three dimensional space. That is the kind of thing that can be constructed, and the bars are interchangeable with habitable modules.

GROWTH MOST IMPORTANT DESIGN REQUIREMENT

I conclude that growth is the most important design requirement. Growth with a few standardized elements permits a modest start with unlimited expansion and shape-changing possibilities. It permits early IOC and reduced funding peaks.

The ultimate program can be much larger and more effective if at the start it is planned extensively but procured incrementally. Few basic parts means cost reduction from higher production, as a start, and a better product, because effort can be focused on refining these few elements.

The cost, the effectiveness, the reliability, safety and value of the system are determined by the design, not the words. All we have at this

point are words, their meaning not being substantiated by the design for the reasons I pointed out. Those conditions are fixable, but I would think in 2 years of a phase B study they should have been fixed by now.

While the company that employs me has received most of the adverse publicity in the papers, let no competitor consider himself blameless for the decadent condition of the industry. There is plenty of blame for everyone. The problem now is how to keep the cancer from resuming its previous rate of growth.

Even at its most succinct, this story is neither short nor simple and a great deal of straightening out is in order before space station can be considered on track.

Thank you.

Senator PROXMIRE. Thank you, Mr. Harwood.

[The statement of Mr. Harwood follows:]

STATEMENT OF OLIVER P. HARWOOD

I am here on behalf of other engineers (mostly anonymous) employed, like myself, in the aerospace industry. My interest is evident to anyone who might read my article entitled ***An Evolutionary Space Station Architecture*** , an article which was published in the Journal of the British Interplanetary Society (July, 1985, issue) and recently brought to public attention in the Los Angeles Times. I will state my case as succinctly as possible.

My Credentials

- 64 year old Structural/Mechanical/ Configuration designer with 43+ years in aerospace.

- Originator of the grid construction in Skylab, a design intended for physical integration of the subsystems in that program, a design whose performance, in many respects, exceeded original intentions.

- Holder of 3 basic mechanical patents.

- Author of 3 articles on space system design published in the Journal of the British Interplanetary Society - one of them the Space Station article previously mentioned, another a dissertation on the equally timely subject of ***Safe Access to Habitable Pressurized Spaces*** (JBIS, August 1986).

My Position

- Space Station is a **worthwhile enterprise** which should be pursued.

- **NASA's plans for Space Station are wrong** - the design is bad.

  ***Inadequate growth** (and shrinkage) causes too much "up front" cost.

*The system is **unadaptable** - too many adapters; nothing fits.

*The system is **"configuration" constrained** (a "growth" station's configuration would be long forgotten after 20 years, so "configuration' is the wrong issue; it's the construction system that counts, one which can make **any** configuration).

*NASA has failed to recognize that Space Station is a **process, not an event**

☐ The system described in my article offers the desired growth and adaptability, would be **simpler to develop** (only **6 main elements**), and could be **operational after 4 launches** with a starting capability roughly equivalent to Skylab. An estimated 50 per cent cost reduction is attainable, especially at the funding peaks. An eventual 100-fold (or more) growth is foreseen. Funding can be steady and incremental over the life of the program, a life of at least 20 years and quite easily more.

☐ Aerospace industry resouces and **capabilities are being squandered** by "rubber stamping" NASA designs instead of seeking independent and competitive solutions to system problems. Why are the "artist's conceptions" of 8 major corporations so nearly identical? In a real competition seeking real answers there would be (as in the past) a different version for each of them - Lockheed, McDonnell-Douglas, Rockwell, General Dynamics, Grumman, Boeing, Martin-Marietta, and TRW. Surely, **someone** must be thinking and unable to get his ideas out.

☐ When NASA was in its infancy (in the early 1960's) it possessed some of the residual arrogance of the bureaucracies from which it was formed, with considerable augmentation from the billions of dollars of public funds entrusted to its care. However, generally lacking experience in design and development of hardware, it allowed industry to handle these tasks, reserving for itself the right to review and criticize. In this mode of operation, there was a balance and the damage from the agency's interference was minimized.

However, **he who holds the gold makes the rules**, and the situation today is quite different. A friend of mine working on the Space Station project identified a problem and suggested a possible solution only

to be told by his supervisor, "On this program, **we don't solve** problems; **we evaluate** NASA's solutions to problems." The objectivity of such evaluations is left to the imagination. One can also imagine how much real industry participation the U.S. public has received for its money.

It's not hard to understand why American competitiveness and the alleged American technological lead in space are in deep trouble.

☐ **The present course should be stopped**; there's no point in being on schedule when there is a washed-out bridge up the line. Since, in spite of time and expenditure, there has been no real Phase B study, 4 or 5 such studies should now be awarded, throwing out restrictive ground rules and eventually narrowing the field to 2 or 3 Phase C/D finalists. Any one of these competitors should be able, unfettered, to accomplish more in six months than has be done in the past two years. Nobody is ready for hardware yet. Let the final winner be the prime contractor. Even at "this late date" **time would be saved** by some such move.

☐ The procurement and management plan is a disaster, a major contributor to the poor quality of the design. This means that the requests for the aforementioned proposals should emanate from headquarters with center responsibility assigned **after** the development plans are sorted out.

☐ The Banks Committee recommendation for Space Station redesign was the right idea, even if the alternative suggested was not. As a NASA official stated in response, "How can NASA admit that after 15 years and $600 million they don't know what a Space Station is ?" Apparently, **someone** (maybe Congress) has to say it for them.

<u>My Involvement</u>

☐ Mid-1983: Pre-phase B advanced design assignment to develop modules for Shuttle which could "evolve" into an embryo space station (NASA- JSC "backdoor" approach in the absence of funding)

☐ Review of a decade of inadequate study results, wheel-spinning.

☐ Discovery of the need for a space lattice system to anticipate unforeseen and unforeseeable future needs, choices narrowing rapidly to the tetrahedral form, the only triangulated system made from elements of

equal length (constructable with toothpicks).

- Discovery of appropriate hub geometry, indexing, orientation.

- Early 1984: Definition of the 6 basic elements (5, if all hab. modules are the same size).

- Eight internal presentations made to advanced design, newly appointed space station program chief engineer, directors, division president, proposal team, requirements group. (Generally favorable reception, no feasibility flaws identified, people asking, "Why not?")
Result: **No** evaluation or support; **no** mention in proposal; no referral to NASA. No further participation in program on my part.

- Not to waste the effort, the material was assembled and submitted to the British Interplanetary Society with subsequent publication. (July 1985)

- The article was sent to Senator John Glenn who forwarded it to NASA-JSC. The NASA "evaluation" said, in efffect, "Don't bother me; my mind is made up." (Frivolous response, to say the least).

<u>My Rationale</u>

- The JBIS article was intended to be constructive criticism, offering a better alternative without carping about or identifying the shortcomings of the official plan. It produced no results.

- The idea was that if a United States start is 8 years behind the Soviets, that start should be as advanced (and ***advanceable***) as "Yankee ingenuity" could devise. "Me, too" (what NASA was, and is, doing) is not good enough.

- The concept was to be an extension of the growth and adaptability features initiated on Skylab, but benefiting from subsequent experience and new opportunities. The current effort has pieces that don't even fit (see sketch of Geometric Random Number Generator).

Conclusions

- Growth is the most important design requirement.

- Growth with a few standardized elements permits a modest start with unlimited expansion and shape-changing possiblities. It permits early IOC and reduced funding peaks.

- The ultimate program can be much larger and more effective if, at the start, it is planned extensively but procured incrementally.

- Few basic parts means:

  - cost reduction from higher production
  - a better product because effort can be focused on refinement.

- The cost, the effectiveness, the reliability, safety and value of the system are determined by the design - not the words. All we have at this point are words, their meaning not being substantiated by the design.

- While the company that employs me has received most of the adverse publicity in the papers, let no competitor consider himself blameless for the decadent condition of the industry ; there's plenty of blame for everyone. The problem now is how to keep the cancer from resuming its previous rate of growth.

Even at its most succinct, this story is neither short nor simple. A great deal of straightening out is in order before Space Station can be considered on track.

O. P. Harwood

Journal of the British Interplanetary Society, Vol. 38, pp. 305-314, 1985.

AN EVOLUTIONARY SPACE STATION ARCHITECTURE

O.P. HARWOOD
Huntington Beach, California, USA.

A space station, an investment in permanent space occupancy, is justifiably concerned with evolutionary growth, adaptability and interchangeability. The system proposed here for its construction is based on the premise that whatever configuration is first launched will be found less satisfactory than envisaged in ground-based studies. At this point, re-arrangement would be preferable to starting all over again.

To assure construction of any shape (or any size) of assembly, the system is a trusswork of equal-length bars, habitable modules interchangeable with struts. There are six standard units and no adapters. The key element is a nodal sphere made from 12 identical sub-assemblies, each corresponding to a face of a bulged rhombic dodecahedron. Each port includes a berthing mechanism that allows lateral engagement.

Habitable modules are integrally stiffened shells with standard patterns of attachment fittings for equipment installation, an extension of the concept that transformed a Saturn S-IVB stage into the Orbital Workshop of Skylab.

External appendages (antennae, solar arrays, etc.) plug into ports in the nodes at the assembly's edges, while hangar spaces are multi-cell volumes inherent in the lattice. Clocking and identification of the port interfaces assure correct assembly.

Not an alternate configuration, the construction system could build any of them.

1. INTRODUCTION

The Space Station will differ from previous space programmes by being not only re-usable but continuously in use. Since it will be revisited regularly and can therefore be frequently up-dated, it does not require advanced and risky technology at the outset. However, it must inherently possess adaptability for new technology as it develops. It is imperative that this capability be achieved without rebuilding the basic framework. This means that initial priority should be given to mounting provisions, distributive systems, standard interfaces and basic geometry.

This paper offers a system designed to meet these specifications. Not intended as an alternative to any Space Station configuration, it is a means to constructing any of them and, if necessary, converting from one to another. Developed initially as a set of modules for long-duration Shuttle Orbiters, the system was expanded to "evolve" into an embryo Space Station. Attention has therefore been focused on general construction rather than specific forms.

Earth-bound fabrication activities such as cutting, drilling and trimming produce chips that are swept up and discarded after falling to the floor. In space, they produce floating clouds of dangerous debris. Similarly, loose bolts, nuts and washers, if lost, threaten the reliable operation of machinery. Clearly, standardised, pre-installed attachment provisions and captive fasteners must be emphasised.

Skylab experience offers precedents for such standardisation. The walls and partitions built into an S-IVB hydrogen tank to make an Orbital Workshop were made of open lattice grid, a regular pattern of nodes 107 mm apart at the intersections of bars forming equilateral triangles. The construction was open to drain hydrogen fuel, since it was originally intended to function as a working stage. The triangular form was necessary for carrying shear loads across an open trusswork. Figure 1 shows a typical installation of equipment and the S-IVB that was modified to house the living and laboratory quarters. It is evident that any installation on this standard "pegboard" could be removed and replaced by any other equipment designed to fit the pattern without the cost and delays from negotiating changes in a structure designed without these accommodations.

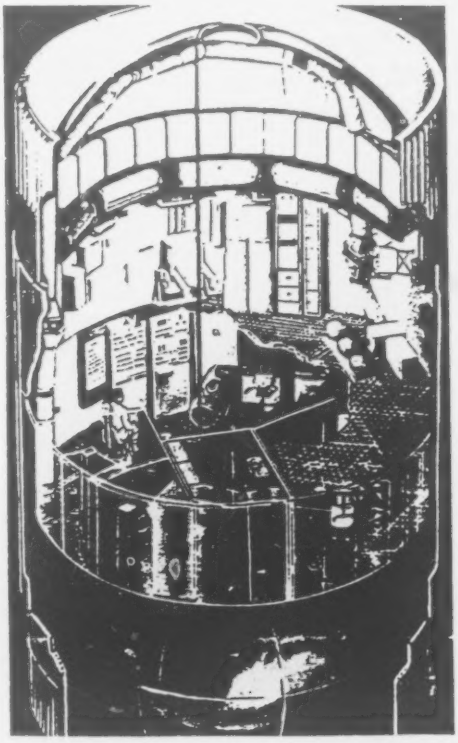


Fig. 1. The Skylab Orbital Workshop, showing the grid floor.

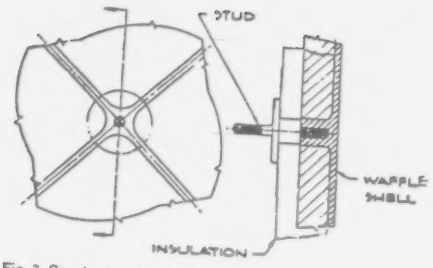


Fig. 2. Standard stud in S-IVB tank waffle node.

The whole habitable frame and associated equipment (about 17,000 kg) was suspended from the waffle-stiffened S-IVB cylinder. Fortuitously, this structure contained about 2,000 attachment opportunities at the intersections of stiffening ribs. These were exploited by installing a stud in a tapped hole at these locations (Fig. 2).

In this case, the tapping operation was a pre-launch rework; for a space station, such provisions must be designed in at the start. The discovery of inherent accommodations accidentally offered by the structural arrangement was, in Skylab, followed by intentional inclusion of similar capability in the added structure. If Skylab had not fallen out of orbit before it could be re-boosted, it would even now be able to accept new equipment in exchange for the old. For the Space Station, better initial planning should provide even more versatility.

It is obvious that the growth and adaptability so desired in the installed subsystems must also be a prominent and planned feature of the subsystem that supports all of them: the structure. In fact, it should start there. Structure, in this sense, connotes "architecture" and all that implies: space allocation, protection, accessibility and maintainability, along with its more obvious role as a sustainer of loads.

In response to this compelling logic, the system here proposed for space stations:

- Is not an alternate configuration: it implements any of them
- Can fill all of space - or any part of it
- Has elements sized by the Shuttle payload bay
- Is structurally efficient, its growth and controllability not being limited by low natural frequency
- Uses only six basic construction units with standard interfaces and component mounting provisions
- Considers pressurised modules and construction struts interchangeable parts of a common lattice
- Permits evolutionary growth, shrinkage and reconstruction in another form *after* initial operation
- Requires little new technology at the start but can accommodate any that develops later

To summarise, this system is not only "technology transparent,' as requested, it can also be called "configuration transparent."

2. GEOMETRIC CONSIDERATIONS

If a large space lattice is to be truly versatile, it must be able to assume any shape. To do this, it must consist of identical cells or cell groups endlessly repeatable. If the edges of such cells are equal-length elements (a desirable condition of standardisation), two basic systems are derived:

- Cubic: square faces and corners
- Tetrahedral: equilateral triangles

Both forms can be modelled three-dimensionally, as shown in Fig. 3.

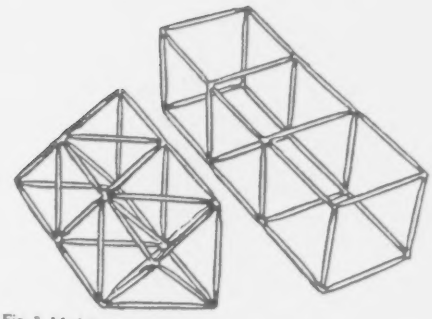


Fig. 3. Models of cubic and tetrahedral space trusses.

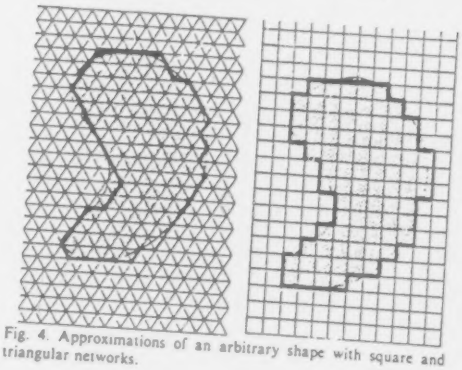


Fig. 4. Approximations of an arbitrary shape with square and triangular networks.

To explain space networks in a two-dimensional manner, square and triangular area arrays are depicted in Fig. 4. The small patches shown can be expanded infintely, if necessary. Their three-dimensional equivalents are cubic and tetrahedral lattices. The latter is somewhat misnamed because space cannot be filled with tetrahedrons. Bars running in the same six directions as the edges of a tetrahedron divide space into tetrahedrons and octahedrons in the ratio of two to one. However, the nodes are all identical; 12 bars converge at each intersection.

As indicated, an arbitrary shape can be approximated with either array, though the triangular one, running in three directions instead of two, can more closely approximate the slope of the figure's outline.

For any large space structure, the Space Station included, the tetrahedral truss is structurally superior to the cubic form because triangles are inherently rigid and stable. A cubic lattice is made stable by adding diagonal struts or cables, thereby creating triangles; but in this case the lengths

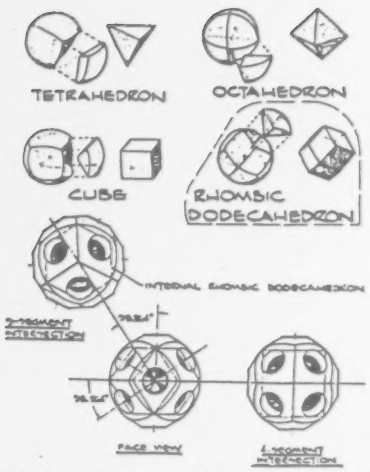


Fig. 5. Polyhedral subdivisions of spheres and a spherical node for a tetrahedral lattice.

are different. So, for a cellular system or a crystalline lattice, the rational choice is tetrahedral, both for large frames and for clusters of habitable modules. Inconsistency of geometric arrangement implies sets of cost-incurring adapters.

The apparent popularity of cubic cells may stem from a universal understanding of the geometry at an intersection. It is also obvious that the polyhedron that presents a face normal to each of the lattice bars is a cube. It has not often been recognised that a pressurised node with no preferential directions of strength (as in an infinite lattice) needs to be a sphere divided into six identical bulged patches, the projections of a cube face on a surrounding sphere. Instead, most airlocks have been cylinders, or intersections of them.

What has rarely been recognised is that for a tetrahedral lattice there is also a polyhedron with a face normal to each incoming bar on which an interface can be centred. Figure 5 shows some polyhedral subdivision of spheres. The cubic version has already been mentioned. The form of interest for the tetrahedral lattice is the rhombic dodecahedron. Not generally known to designers of large space structures, it is well enough known to students of polyhedrons to have been given the name it bears. In a close hexagonal packing of spheres in space, where 12 spheres are in contact with a central one while touching each other, the planes of tangency at the points of contact around the central sphere are the faces of a rhombic dodechedron. It, like the cube, when packed against others of its kind, completely fills space without voids. This seems to be a necessary characteristic for the node of a universal space-filling lattice. The literature indicates that this polyhedron and the cube are the *only two* with identical faces that possess this property.

A model of this shape at a tetrahedral nodal intersection is shown in Fig. 6. It is the key element in an endlessly repeating lattice system which, by its ability to fill all of space, can also fill any part of it. Thereby, it permits the construction of any space station configuration or, for that matter, an assembly to carry explorers to the vicinity of Mars.

The foregoing discussion treated nodes in the lattice as a given condition, although the existence of such units has been the subject of debate concerning the question of affordability. Without any formal economic analysis, this uncertainty should be settled by rational discussion. Firstly, a node should be expected to function as an airlock and a space station without airlocks is unthinkable. In addition, even the simplest two-dimensional array (the square one

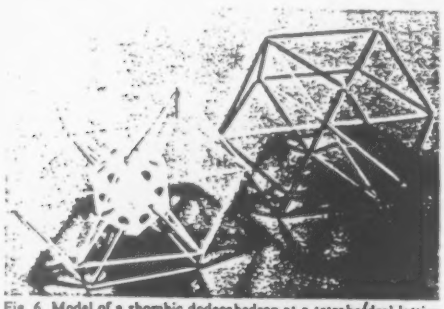


Fig. 6. Model of a rhombic dodecahedron at a tetrahedral lattice node.

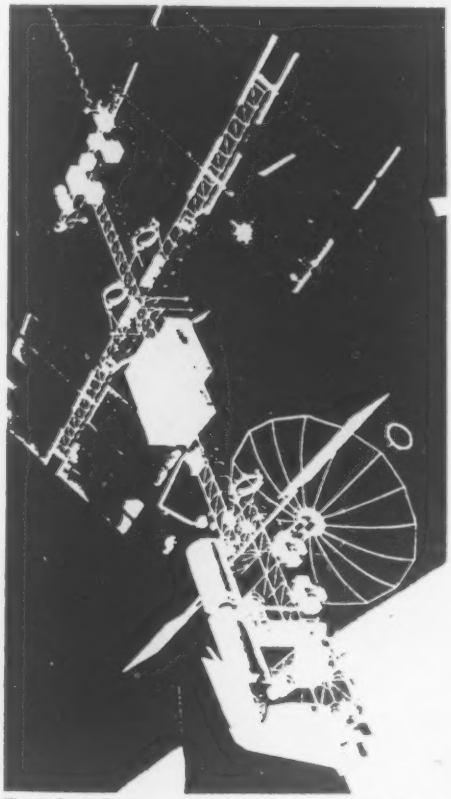


Fig. 7. Space Station study reference configuration, the "power tower."

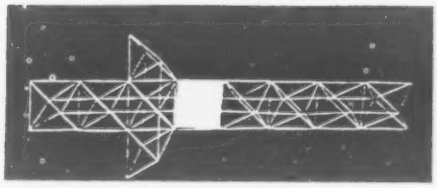


Fig. 8. Representation of a tetrahedral "power tower."

shown in Fig. 4) has intersections where four bars meet. Each bar has two end connections. Therefore, to come out even, the infinite array must have twice as many bars as junctions. The triangular array has three times as many bars as intersections, and a three-dimensional tetrahedral lattice requires six times as many bars (or modules) as nodes. Therefore, for universal adaptibility, nodes cannot be integral with bars because the required numbers of each are different. Growth would be restricted and more nodes (or the equivalent) would be procured than are required.

3. APPLYING THE CONSTRUCTION SYSTEM

The Space Station depicted in Fig. 7 is the initial all-up configuration of the so-called "power tower." This design is the reference for the definition phase Space Station studies. It features a deployable structural main frame that links appendages such as power-generating arrays, experiments, hangars, antennae and habitable modules. The external size differences between initial and growth versions is small. Chiefly, the power-generating systems switch from solar cells to heat-cycle turbines, the number of pressurised modules increases and the main frame is reinforced with parallel beams. Increases in mass and technology state are not matched by size or shape changes in basic architecture. Deployable mainframes do not permit it.

The design's counterpart in the construction scheme proposed here is shown in Fig. 8. This is a model of the main frame; appendages are not included. While the overall arrangement is essentially the same, there are basic detailed differences:

- The core structure is erectable, not deployable, each bar representing a span of 17.76 m.
- Some of the bars - any appropriate clustered group - are habitable modules with attendant nodal airlocks.
- Appropriately scaled up, the assembly as shown is 134 m long with a span across the stub arms of 50.3 m. The deployable power generating equipment extends beyond these arms, supported on rotary bearings.
- Hangars are screen-enclosed octahedral cells of the core, one such opportunity being shown on the model. Each hangar cell has a volume of over 1700 m³, accessible through a triangular door (one removed side) 15 m wide by 13 m high. Probably four or five such cells are usable as hangars in the size of assembly shown, though the core itself can be expanded indefinitely.
- An assembly of this size and form is made from 120 bars and 40 nodal joints, both of variable composition. In all, 240 connections must be made after the bars are made up and transported to the assembly point. The connections are built into the standard units with no loose parts and no adapter brackets.

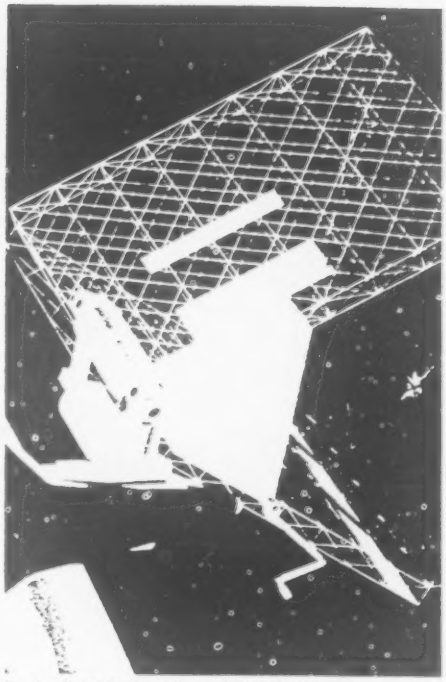


Fig. 9. "Delta" configuration studied by NASA.

A now-discarded configuration that received considerable early attention is the "delta" space station (Fig. 9). As designed, its three deployable structural panels each contained about 1600 members, almost 5000 altogether, including splices. It was designed this way "to minimise EVA" as stated in the final report. While this statement may be true for an identical design, one intended to be erectable would be expected to entail much fewer and larger elements.

Figure 10 shows another model representing the "delta" design as built with the tetrahedral truss system. As expected, while it is about 47 m high, it uses only 147 bars and 51 nodes. As many as 10 of the bars are standard pressurised modules, interconnected through six nodal balls; the rest consists of standard struts and corresponding nodal fittings. Unoccupied nodal ports are available for EVA, docking and accessory modules. As the manned portion of the station increases in size, bars and nodal connectors can be replaced by habitable modules and nodal airlock balls.

Solar panels on top of the configuration are assumed to be NASA-developed fold-up panels contained in split boxes extended by an "astronaut" or the equivalent, stretching the solar blanket between box-halves. In this case, the panels are double blankets 7.9 by 33.5 m in size; there are 16 altogether, providing about 4250 m² of collection area for 400 kW or more of power. The arrays do not all have to be there at the start, nor does all the structure. Between the solar panels and the occupied modules at the apex of the delta is a hangar space made by removing structurally unnecessary bars from the centre; it is a large octahedron

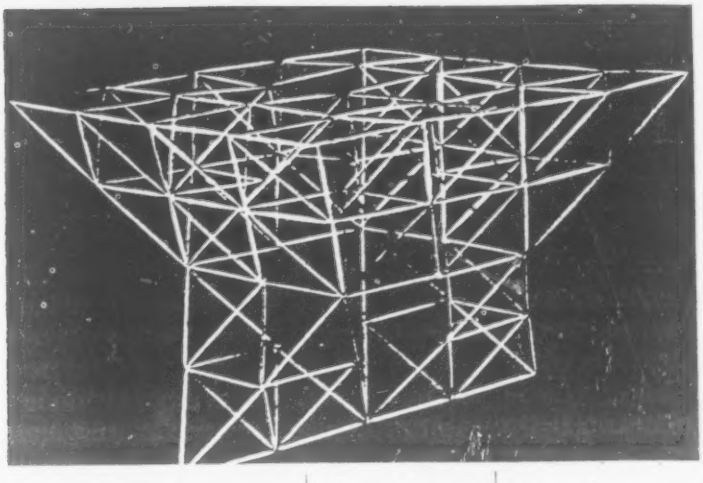


Fig. 10. Tetrahedral version of the "Delta."

with 33.5 m edges. Its volume is about 10,500 m³. Note that slices at appropriate angles through the lattice uncover square patterns where they may be needed.

4. ELEMENTS OF THE SYSTEM

The "meccano set" for a universal tetrahedral construction system consists of six basic units (five, if a habitable module is always made in a single size). At least three of these elements make up each of the assemblies in the configuration models. Figure 11, showing how the standard 16.76 m spacing is filled by standard units, identifies the first three elements, as follows:

1. Nodal Airlock. This is the spherical entity subdivided into 12 identical rhombic subassemblies that is the key to the lattice geometry and provides ports for EVA, docking or accessories.

2. Habitable Module Cylindrical Barrel. This is the standard shell segment for all habitable modules: laboratories, command centres, sleeping quarters or workshops. Each segment's length is the same as the distance across opposing flats of the nodal ball to allow the combinations shown. The assumed diameter is 4.32 m.

3. Habitable Module Cone End. This unit closes out habitable spaces, incorporating at its narrow end the same attachment and functional interface as must be built into each of the 12 faces on the nodal ball. Its 60° conical shape is determined by the equilateral triangular relationship with adjacent units.

Where the structural frame extends beyond the inhabited volume of a space station, the node-to-node spacing is maintained by the remaining three standard elements.

4. Half-Strut. This unit is a tapered structural column with androgynous connectors on both ends. Its length is half that required to reach between structural cluster fittings at the nodes ("hedgehogs").

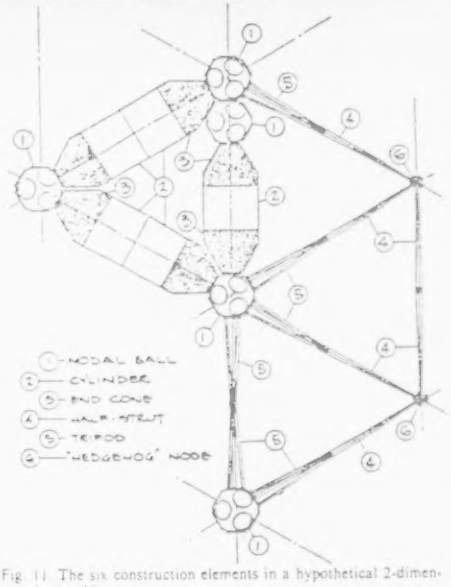


Fig. 11. The six construction elements in a hypothetical 2-dimensional assembly.

5. Folding Tripod. All ties between pressurised units and the open structural frame are made through this unit. Its length is half the distance between the opposing faces of two nodal balls. It combines with a half-strut when the elements at the nodes are dissimilar.

6. "Hedgehog" Cluster Fitting. This is an assembly with 12 stubs identical to the androgynous ends on assembled strut pairs. The stubs are geometrically related in the manner of faces on airlock nodes.

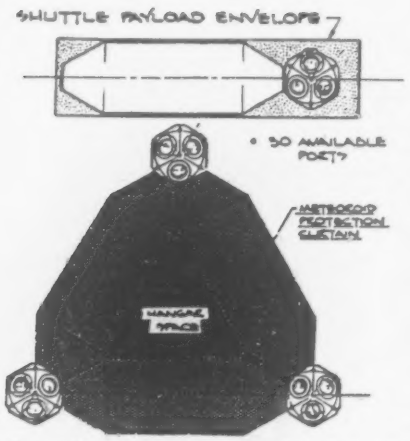


Fig. 12. A minimum closed configuration carried in three Shuttle launches.

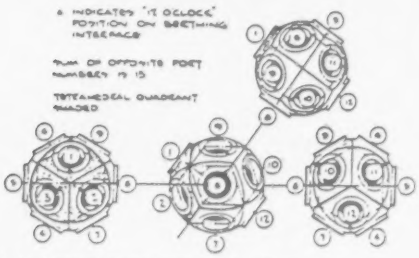


Fig. 13. Nodal port "clocking" and identification.

The system is sized by the assumption that one Shuttle load consists of one airlock ball and one full-sized 13.4 m habitable module as shown in Fig. 12. For the start of a space station, the first launch should probably orbit a power module complete with attitude controls and a small propulsion system. When the following three launches bring up three bay-filling payloads, as shown, a minimum system can become operational. This small system could barely sustain a 2 or 3 man crew between resupply visits but it would be a start.

The 12 port node is the determinant of the construction when its 12 identical sub-units are properly identified. The orientation and labelling of the faces for this purpose are shown in Fig. 13. It starts with a 3-face patch forming the spherical projection of a face of a tetraherdron. There are four such groups to a ball. As illustrated, the groups are 1-2-3, 5-6-11, 4-7-12 and 8-9-10.

Note that the "12-o'clock" angular position of each port is pointed toward the centre of the group, most clearly shown in patch 1-2-3. When this procedure is followed for all four patches, the opposing ports on the ball are always oriented in the same direction. Therefore, nodal balls spatially oriented in the same manner always correctly align with cylindrical modules whose ends are also "clocked" alike.

Assembly aligment can be automatically assured when the polyhedral faces are numbered like cubical dice (whose opposite face numbers add up to 7); for a 12 faced entity like this, the sum of opposite face numbers is 13. Thus, when a habitable module end is plugged into port 5 of a ball, its opposite end fits port 8 of the next node. The proper assembly of any space station arrangement can be defined unambiguously in this manner.

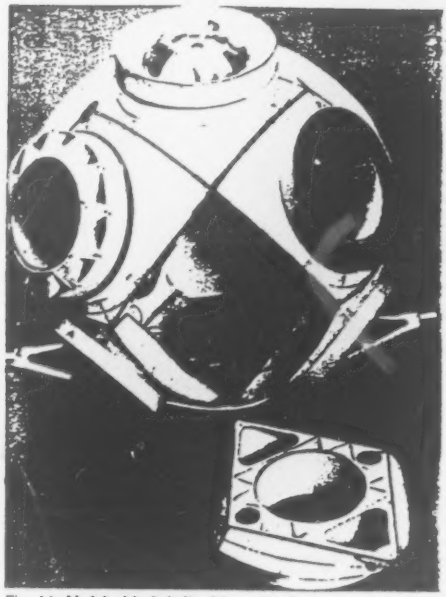


Fig. 14. Nodal airlock ball with standard sub-assembly (lower right) and accessories - thruster group and battery pack.

5. NODAL AIRLOCK BALL

In a lattice assembly of habitable modules interconnected by spherical nodes, any nodal unit is an airlock. As such, it must be sealable to prevent loss of the breathable atmosphere. This, in turn, leads to a requirement for inward opening doors, one for each penetration, or 12 in the element appropriate for tetrahedral truss geometry. In the airlock photograph shown in Fig. 14, one of the 12 identical subunits is shown removed (at lower right). Accessories shown plugged in include a 4-thruster propulsion unit and a suggested battery pack.

A spherical shape is indicated for good reasons, not the least of which is that a round door covering a circular opening fits well against the spherical shape near the opening. Internal space is less likely to be cluttered with unstowable hatches. Spheres are, of course, the most efficient form of pressure vessels, while their compound curvature also makes them resistant to compressive forces. Circular holes in spheres also remain round and planar under pressure, simplifying the problem of maintaining an effective seal.

Figure 15 shows in some detail how a rhombic subassembly can be constructed. It is double-walled for a rigid docking interface. In addition, the curved and planar surfaces enclose a space through which system runs (wiring, fluid lines, etc.) can be routed and interconnected. Since the inner polygon is a machined open grid lattice, it not only

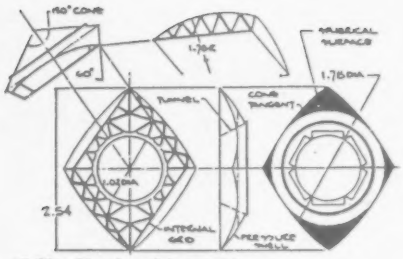


Fig. 15. Rhombic sub-module assembly.

protects and supports these system runs but allows access to them. Integral to these panels is a door jamb and sealing surface. Twelve identical units like this form a 3.56 m diameter sealed ball. The diameter selected is the minimum required to stow hatches between 1.02 m openings without encroaching on them. For larger openings, proportionately larger nodal balls are required, this enlargement being limited by the clearance in the Shuttle payload bay.

Although it has not been indicated, a further intention for adaptibility, is some form of socket, stud or similar attachment opportunity at each of the 14 "corners" of the structural ball. At these points, inner and outer structures converge, offering locally high strength. While there is no specific requirement for such provisions, the opportunity, if offered, will almost certainly be used. If passed up, it will be difficult to add later.

Since the lattice intersection must accommodate as many as 12 attached modules, nodes at the edges of any configuration offer many unoccupied ports, usable for docking, EVA or standard plug-in accessories like the previously-shown propulsion and storage units, or tanks for consumables or antennae. Any accessories, once developed, are directly transferable to another port, another module or a different configuration.

It is obvious that an adaptable nodal shell can be used in many ways. It could be a manned module for a recovery, repair and service vehicle. With nearly 11.5 m^3 of volume inside the inner polyherdon, it could be fitted for life support of a four man crew for ten days to two weeks. Essentially the same vehicle can serve at a space base as a rescue "lifeboat." Among the accessories that could be developed for this role is a remote manipulator turret.

Figure 16 illustrates a proposed docking/berthing interface for this system. The type developed for Apollo is unsuitable because, projecting beyond the interface plane, it prevents lateral approach; it fills the tunnel, requiring disassembly before use; and the mating faces are different. The single-use Apollo/Soyuz device, although androgynous (both sides identical), also projects awkwardly across the interface plane.

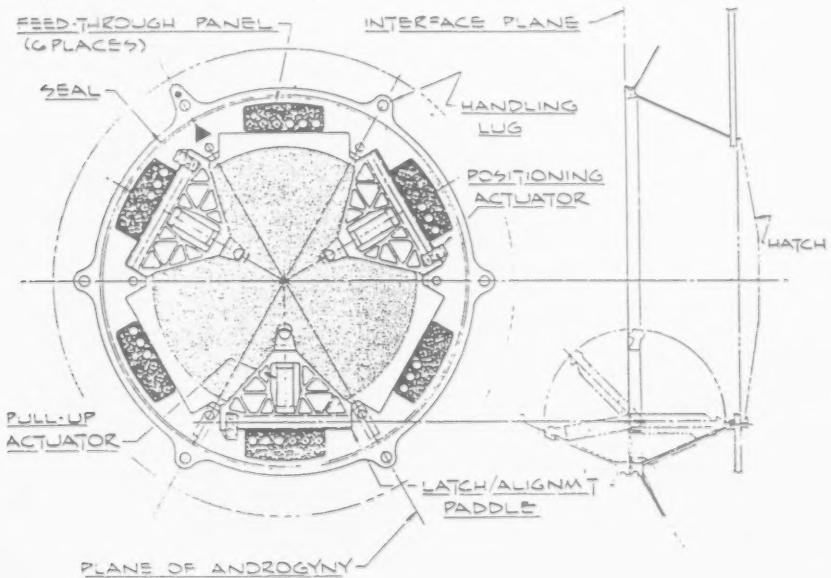
These precedents and the unique problems of this closed system combine to define the docking requirements:

- Androgynous (one system to develop)
- Flush faces for lateral engagement
- Positive guidance for head-on encounter
- Light connection before pull-up
- Minimum size and weight (many identical ports)

An added feature proposed for this mechanism is retractability to move out of the way when a port is occupied by an accessory module.

As a consequence the suggested method features *inward-*

Fig. 16. Docking/berthing interface for lateral assembly.



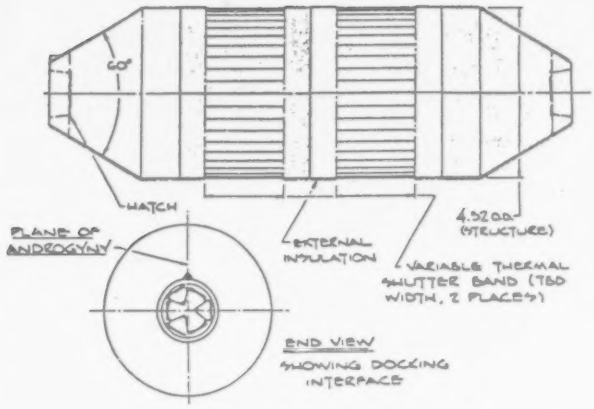


Fig. 17. Universal habitable module.

sloping triangular paddles, motor-driven through a range of positions appropriate to each operational mode. With hooks at their ends, they also perform the latching function by reaching through the opening in the opposing interface and engaging sockets in the tunnel wall. When fully engaged and locked, the paddles from both mating units lie inside the opposing tunnels, leaving a clear passage available for immediate use.

For a typical head-on docking the paddles are extended at an angle such as 45°. As the interface planes near each other (approximaely 25 mm short of complete closure), a spring-loaded detent hook (not shown) prevents recoil while the paddles further expand to engage. After the hooks enter sockets in the opposing tunnel wall, a pull-up actuator in each paddle rigidises the connection.

As the figure shows, the paddles can be positioned anywhere in a range exceeding 180°. For lateral insertion into the structural stack, the paddles are flush with the interface plane or below it. As soon as the mating units are approximately aligned, the paddles extend to centre the connection and continue to the engaged position. When withdrawn completely into their own tunnel, the paddles and latches are out of the way of an installed submodule whose attachment points can be the six spots shown at the hinge ends.

The paddles are driven to any commanded position by worm drive actuators located at the end of the hinges and bussed together by a chain, perforated tape or similar drive girdling the tunnel. Each actuator is indirectly connected to the paddle it drives by a spring and damping system built into the base hinge.

All of the mechanisms described and the dimensions assumed are tentative and subject to revision as a result of further study or such approvals as will be required for an international standard. Whatever develops will become an international standard, one that is long overdue.

6. UNIVERSAL HABITABLE MODULE

The habitable module required for most Space Station functions seems to be close to the same length and diameter as the now-operational Spacelab, but while Spacelab has been funded and developed, its design has been concerned with a single unit (of variable length) compatible with the Shuttle Orbiter payload bay. Little thought has been given to clustering multiple units into space station assemblies; particularly, the end geometry does not lend itself to assembly in any way but tandem. To a considerable extent, the thinking applied to all previous manned vehicles has concentrated on making one unit work. Much of this thinking can, it is hoped, be applied to the module introduced in Fig. 17.

Shaped for the tetrahedral truss assembly method, this module has relatively long conical ends with converging space which, if intelligently used for service functions, should be no disadvantage. The module is envisaged as a stiffened shell with entry only at the ends; any exposure or exit to the vacuum of space or to other modules is through airlock nodes at the intersections. Except for circumferential bands with thermal control shutters, it is completely covered with multilayer insulation of any appropriate variety.

Since a leak-tight presurised canister with this much volume, once built, should find many useful applications, the structural shell has been designed to maximise adaptability and usable volume. Typical shell construction for both cylindrical and conical sections is shown in Fig. 18. The integral external stiffening ribs form an isogrid array of equilateral triangles with intersection nodes spaced about 180 mm apart. The panels are machined from large aluminium alloy plates about 20 mm thick, leaving a skin of about 1.5 mm between ribs. Each nodal intersection incorporates an outer socket and inner button for all the attachments to the shell. A suggested detachable captive collet fastener for all interior attachments is shown in Fig. 19.

There are no frames in this construction, not even where transportation trunnion fittings are attached. Frames are avoided because these fittings introduce their loads into the shell tangentially at patches with enough fasteners to match the load-carrying capacity of the nodes. No additional shell reinforcement is expected, though it can be provided if necessary by leaving enough extra material in the machined plate. The trunnion fittings, needed only for transport, are removable, being attached by the releasable fastener shown in Fig. 18.

The versatility of this construction is further demonstrated by a standard window construction (Fig. 20). Instead of removing the whole shell area, only the skin between stiffeners is cut out - in as many pockets as viewing requirements dictate (16 in the example shown). The outer edge is sealed

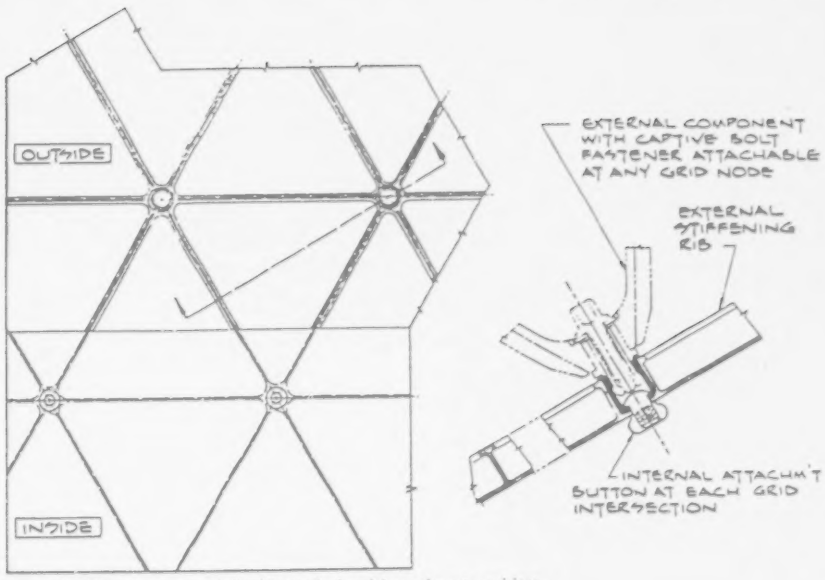

OUTSIDE
INSIDE
EXTERNAL COMPONENT WITH CAPTIVE BOLT FASTENER ATTACHABLE AT ANY GRID NODE
EXTERNAL STIFFENING RIB
INTERNAL ATTACHM'T BUTTON AT EACH GRID INTERSECTION

Fig. 18. Integrally stiffened pressure shell with standard nodal attachment provisions.

by an elastomeric molding of appropriate cross section for window retention. Its underside includes sockets that are retained by the ubiquitous internal buttons around the edge. Each of the buttons at nodes in the middle of the window also retains an elastomeric supporting collar. This mid-panel support allows the clear pane to be thinner. Reinforcement to replace the skin removed for vision can be an internal bonded doubler or enlargement of the local ribs if the window location is known before the panel is machined. With the generous structural margins expected for the pressure loads, no reinforcement may be necessary.

This module is larger than those shown in most space station design descriptions. However, having been sized by STS payload bay dimensions and compatibility with the nodal ball, it should probably stay as it is. Any extra volume is sure to be found useful after the start of service.

7. CONSTRUCTION STRUTS AND NODES

As has been indicated in Fig. 11, there are three combinations for struts bridging the node-to-node spacing. This is caused by the different size of the two elements serving as nodes; pressurised balls are significantly larger than strut-connecting "hedgehog" fittings. Where there are no habitable modules, the nodal span is covered by two identical half-struts. Between nodal balls, if such a situation is realistic, two tripods are appropriate. When the gap between a "hedgehog" and a nodal ball is filled, the two elements are combined. This means that the middle joint on a tripod must be the same as that on a half-strut. In the nested strut system proposed every two-element column can be made from elements of the kind developed by the NASA Langley Research Center. For the centre joint at the large end of the strut, and in the corresponding position on a tripod, the androgynous multi-fingered joint already developed should

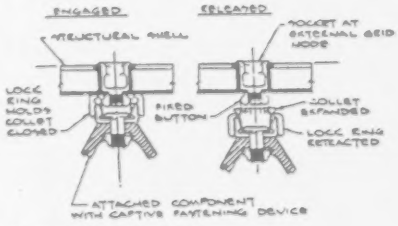


Fig. 19. Standard captive collet fastener.

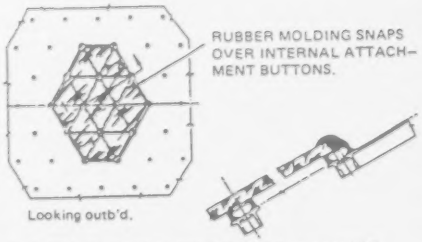

RUBBER MOLDING SNAPS OVER INTERNAL ATTACHMENT BUTTONS.
Looking outb'd.
• SHELL IS PERFORATED BETWEEN STIFFENING RIBS ONLY – NOT THROUGH THEM

Fig. 20. Standard window exploiting attachment features.

be adequate although it may need an additional locking ring on each member to trap the fingers so they cannot spread and release. The small end androgynous joint proposed here is again similar to the Langley design but secured by external sleeves instead of an internal spring latch. It is shown in

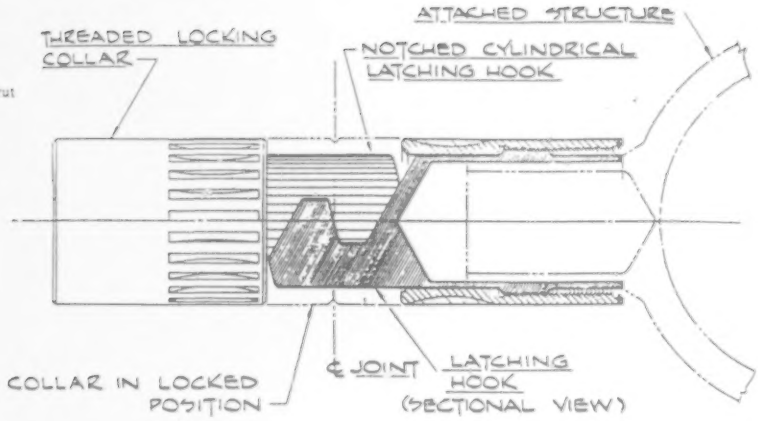


Fig. 21. Androgynous strut end connector.

Fig. 21. This is a well-known mechanism, generally secured by a single outer sleeve. However, since in an androgynous connection both sides must be identical, two threaded sleeves are used. This choice offers a bonus: the two can be tightened against each other to minimise play in the joint. Once the ends are brought together by hand, advancement of the first collar holds the assembly firmly enough to simplify operation of the second collar and subsequent tightening.

The foldable tripod can be attached at three of the six available spots on the docking interface. Since the space between two legs is as wide as the access opening diameter, the port remains usable for EVA and the legs themselves should be useful handholds.

Where construction struts meet at a node, there is a "hedgehog" cluster fitting corresponding to an airlock nodal ball. As illustrated in Fig. 22, the stubs project in the same directions as elements emanating from ball nodes. The "12 o'clock" position at the interface converges on the centre of three-stub groups exactly in the same manner as previously described for docking ports. The same numbering strategy can also be employed here.

As with airlocks, a "hedgehog" is made from identical stubs with rhombic bases. These bases, welded along their edges form the same polyhedron.

As the figure demonstrates, "hedgehog" fittings attached to each other can, by themselves, make a double-faced truss sandwich panel. With appropriate trunnion adapters, the extended assembly should serve well as a cradle for its own transportation to orbit; a pair of these cradles could, between them, support their struts for the ride.

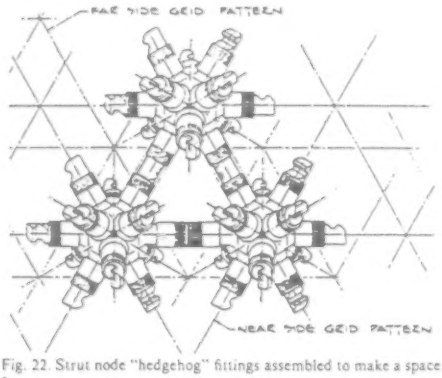


Fig. 22. Strut node "hedgehog" fittings assembled to make a space frame.

8. CONCLUSIONS

The Space Station is a new and different type of programme; it will be a continuing process and not a one-off event. As such, it will demand the characteristics offered by this construction system:

- An efficient structural system which, because it uses the only stable polygon available, the triangle, is inherently rigid; growth is not limited by low natural frequency.
- The adaptability that makes it rebuildable in another form.
- Adaptability to accept a variety of plug-in modules.
- The adaptability offered by structure patterns that physically integrate the subsystems without rework and without time-consuming argument and negotiation.
- The adaptability inherent in structural frame consistency, the construction struts and pressurised units conforming to the same lattice geometry - no extra adapters.
- The economy offered by developing only six interchangeable core construction units.
- The economy of identical interfaces and identical sub-units which, at an early stage, offer the cost benefits of quantity.

While it is desirable to study and understand what a space station must do, and, in the course of such study, to define what the starting configuration should be, this sytem permits major changes of mind after first service and for an indefinite period thereafter. In short, the development of the elements can proceed without a definite configuration decision.

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SAFE ACCESS TO PRESSURISED HABITABLE SPACES

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The loss of vital breathing atmosphere is about the worst disaster that can befall a space station crew. This means that extreme skill and care must be applied to the design of closures for habitable spaces. While the subject may seem like a small detail in the midst of current sweeping system investigations, it is a crucial detail for safe operations.

This paper discusses some of the critical issues in this design area and, more than anything, is intended to head off any trend toward increasing complexity arising from newly-invented hazards, an ever-present pitfall for door designers. In order to keep a pressure hatch simple and safe it is emphasised that the door should function as its own latch.

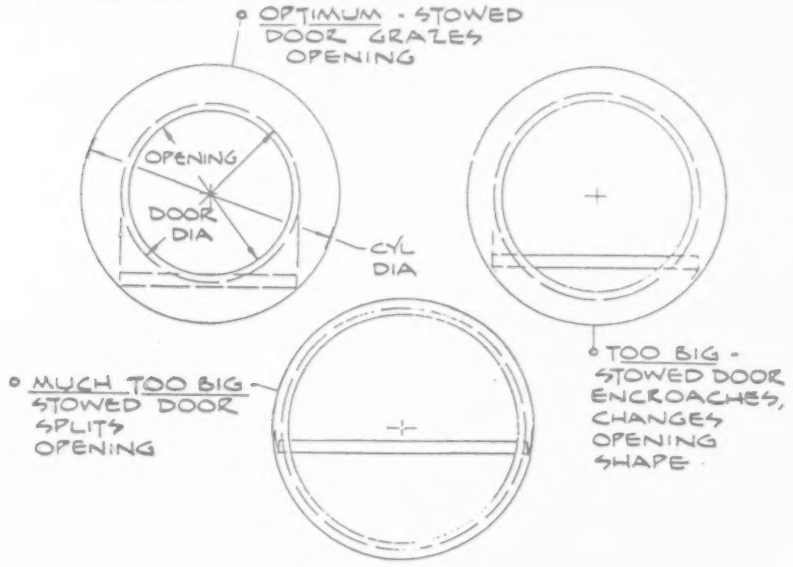
1. INTRODUCTION

Now that funding appears to be at hand for a US manned space Space Station it is timely to think carefully about safe passage between inhabited spaces and the hard vacuum of space. The consequences of opening ports at the wrong time, leaving them carelessly unsealed, or designing a closure which releases too easily can be catastrophic. Loss of life for everyone aboard is a likely possibility.

The problems involved are not insurmountable and many of the needed capabilities are routinely demonstrated in airline operation. In fact, airline (also, aircraft) experience is the kind to draw on for guidance in space operations. The total time of manned occupancy in space has been too short to reveal the weaknesses in designs which become embarrassingly clear during accident investigations. Too many accidents have been caused by closures that opened outwardly too readily. Passengers and crew members have been sucked outside through improperly secured escape hatches, navigation domes, windows and entry doors. It has led to requirements for internally opening doors on most of the current jet fleet. With the advent of the wide-body jets and modular cargo containers, this requirement was relaxed for belly cargo compartments with the result that a DC-10 with all aboard was lost near Paris.

The Apollo crew hatch was redesigned after the fire disaster to be outwardly quick-opening. While this characteristic may have been considered necessary under the circumstances, it is the last option designers of airliners would choose. Fortunately, this hatch, and the Space Shuttle crew door since then, have been operated relatively few times and always by people who

Fig. 1. "Enlarging" openings to reduce the size of the passage.


OPTIMUM - STOWED DOOR GRAZES OPENING
OPENING
DOOR DIA
CYL DIA
TOO BIG - STOWED DOOR ENCROACHES, CHANGES OPENING SHAPE
MUCH TOO BIG - STOWED DOOR SPLITS OPENING

were thoroughly trained and fully aware of the dangers inherent in improper operation. In retrospect, it is also apparent that the Apollo redesign was a somewhat hysterical reaction to a highly publicised event. The accident was mainly caused by an ill-advised ground test employing pure oxygen at dangerously high concentration. This Apollo requirement was just one part of the general "shotgun" activity but left its mark on the requirements for the Space Shuttle.

For a space station, particularly one assembled from modules, there will be lots of hatches for compartmentation as well as assembly joints whose inadvertent release will be just as hazardous as an accidentally opened door or a blown window. With the passage of time, procedures will be relaxed or forgotten, mechanical interlocks and electronic warning devices will get out of order, and an increasing number of untrained or forgetful people will be operating the hatches. The consequences of carelessness will not be as simple as letting flies in or heat out, circumstances which have led to automatic door closers in homes and businesses. Here is where every conceivable shred of ingenuity must be exercised to circumvent Murphy's Law. Adding backup devices on top of preventive interlocks on top of special adjustments and procedures on top of safety devices is no way to get there. Simplicity should be much better.

2. THE RIGHT SHAPE

Notched panels which define a diamond shape and slide past each other to close an opening may provide the proper touch of dramatic entry for a science fiction movie or television show, but simpler devices offer the right example for real operation in space. These are manhole covers which are too large to slip through the openings they seal and injure work crews below. If inwardly opening hatches in space modules are to foil the insidious effects of Murphy's Law, they should also be incapable of passing through the openings they cover. The appropriate shape, in both instances, is round. There are other constant width shapes, some irregular, which can produce the same effect, but they introduce other problems, such as uneven distortion of doors and jambs which make sealing difficult and special orientation which complicates fittings of adjacent units, to name two.

It may be argued (and has been) that such a door inside a closed volume cannot be removed for replacement when the need arises (or even installed after the sealed unit is built). True, but it should not be too difficult to design it to be partially dismantled for this purpose. When fully assembled, it should still be incapable of passing through the hole.

As already mentioned, a round, regular door and jamb edge should offer little of the distortion which complicates sealing. This is possible when a round opening is at the end of a cylinder or cone or similar axisymmetric shape, or anywhere on a spherical surface. It does not work well in the middle of a square or some other polygonal panel, nor on the surface of a cylinder. The consequence of this kind of inappropriate design are not necessarily serious, unless one is nervous about excessive structural weight or difficult mechanical operation. If the door designer finds himself faced with such a problem, it is probable that somebody working at a higher level of design definition has erred.

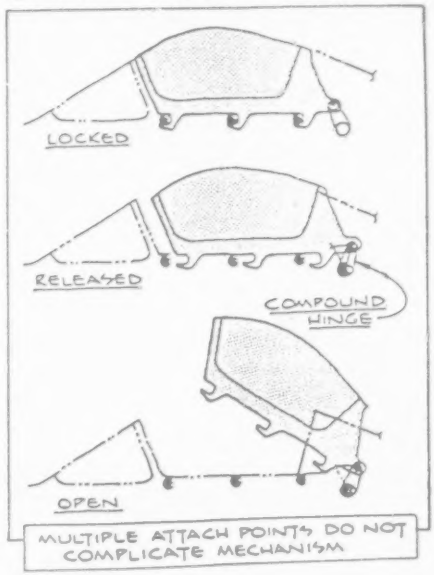
Once again, it can be said that there is an airline precedent for doors in the sides of cylinders, so why not? First of all, they all leak unacceptably for a space habitation where all the atmosphere must be imported. Secondly, they are never operated in flight (except accidentally). Also, their jambs are not the structural hard points where adjacent modules are connected. Besides, if they accidentally pop open, the results are not likely to be quite as serious in most cases. Airline precedent and experience are useful only up to a point.

3. THE RIGHT SIZE

As space vehicles, especially manned ones, and their components become larger, the appetite for larger openings increases. Devisers of requirements can always think of another larger object to pass through an access opening. In some instances, these objects are only used in quite specialised situations, making their accommodation an unnecessary penalty for the rest of the habitable volumes. In other instances, the insertion of the equipment in habitable spaces may not be justified – consider control moment gyros in this category. Rather than size critical openings into a space station by the dimensions of existing hardware, it might be wiser to redesign or reshape the offending articles. After all, space stations can be expected to be around longer than most of the components which might shape them. The Manned Maneuvering Unit (MMU) is a good example which, with relatively painless redesign, could be brought into a pressurised space in three parts, two "arms" and a back piece.

Another difficulty in maximising the size of apertures is that the lids which cover them must somehow be stowed in the internal spaces without blocking the passages. This is exactly what did not happen on Skylab in the Airlock Module. These circular hatches became so large that, once they were lifted off the jambs, there was no place to stow them except back in the opening. The situation is illustrated in Fig. 1 which shows that the ultimate door divides the opening like a butterfly valve. Why the airlock openings became so large is difficult to explain; there was little reason to make them any larger than the port in top of the Orbital Workshop, a reworked S-IVB hydrogen tank. All the structural pieces making up the Workshop were required to be small enough to pass through this 1.02 meter opening. Once the restriction was known and accepted, it created no great hardship. A similar size seems reasonable for a space station. At any rate, a study which takes into account

Fig. 2. A safe outward-opening fighter canopy concept.



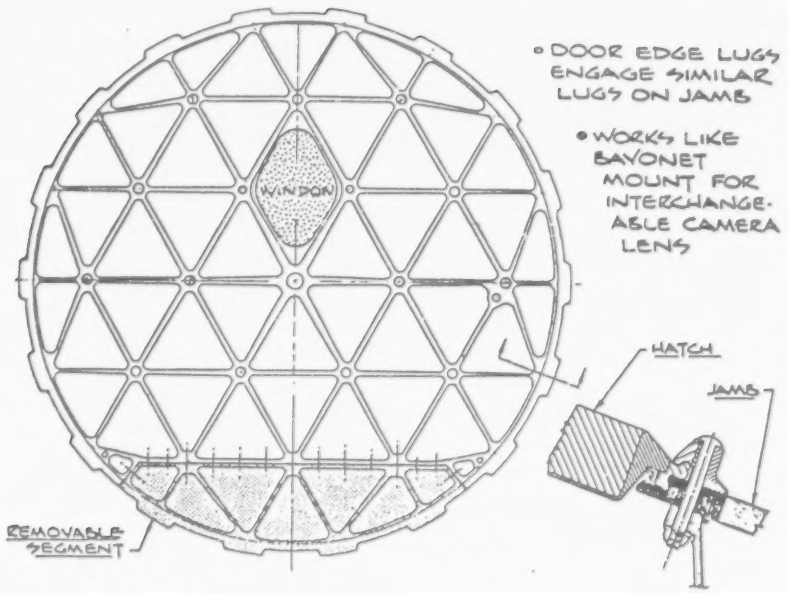


Fig. 3. A round self-latching pressure hatch.

all the previously mentioned factors and further considers the long term effects of any space station decision may reveal that the appropriate size for standard ports may be exceeded by the presently expected minimum.

4. THE RIGHT MECHANISM

The design rules for airliners may specify internal plug doors without introducing any confusion, but for a modular space station or similar compartmented space habitation, it must always be assumed that a barrier between two pressurised volumes can be subjected to pressure from either direction. The plug principle may work adequately in one direction, but, in the other, the door would be hanging on its latches. Perhaps it would not be flung into space if the latches let go, but, with pressure behind it, it could become a very hazardous battering ram. The situation can be likened to an outward-opening canopy on a fighter or a cargo door which cannot be allowed to swing into a cargo container's space.

One solution to this problem has worked quite well in at least one of these cases. This is to make the door itself the latch, suspending it on a compound hinge mechanism (see Fig. 2). A similar concept is found in the inward-swinging, outward-opening doors on DC-8 and 707 transports. No system of interconnected latches, however cleverly devised or accurately adjusted, can offer the safety and reliability offered by having fixed parts of the door behind corresponding fixed parts of the jamb. Another advantage of this technique is that the number of attachment points between door and jamb is independent of mechanical complexity. A closer spacing, that is, more attachment points, can be obtained without redesigning the operating mechanism.

While the closure acting as its own latch works well for doors, it is quite impossible for connections between assembled habitable modules. No way has been devised to rotate a pressurised module at one end to engage it without, at the same time, unfastening the opposite end. In this instance a separate, probably redundant, latching system is indicated. Here again, it is not wise to be overly clever with mechanical gadgets. One mechanism which should be applied with utmost restraint, preferably not at all, is the overcenter toggle latch.

In 1951 this writer had the assignment of designing a latch system for the F4D-1 fighter (at the Douglas El Segundo plant which used to make Naval combat aircraft). The initial product of the exercise was a double-action double-overcenter bundle of mechanical complexity which was duly, and with some pride, presented to the US Navy for routine review and expected approval. It was flatly turned down with the comment that "no 'hair trigger' devices like overcenter toggle latches are acceptable for closures on pressurised volumes." It was back to the drawing board. Unfortunately this gem of good design practice was not heeded in the design of the DC-10 belly cargo door; it had overcenter latches. At least, the experience is worth mentioning to anyone who is responsible for a space station design.

It is recommended, in light of this knowledge, that the appropriate mechanism for joining pressurised modules which cannot serve as their own latches is something more humdrum and conventional like a set of interconnected jack-screws. At least, if prudently designed, they can back off for a considerable distance without letting go. The attendant leakage should be warning enough.

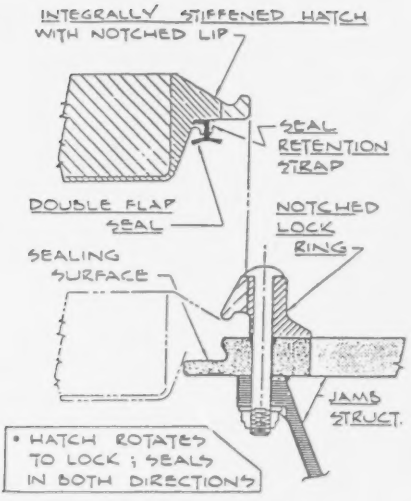

INTEGRALLY STIFFENED HATCH WITH NOTCHED LIP
SEAL RETENTION STRAP
DOUBLE FLAP SEAL
NOTCHED LOCK RING
SEALING SURFACE
JAMB STRUCT.
• HATCH ROTATES TO LOCK ; SEALS IN BOTH DIRECTIONS

Fig. 4. Hatch, jamb, and seal relationship.

5. ONE WAY TO DESIGN A HATCH

From the standpoint of accurate fit, economy, and leak tightness, it is desirable to make a hatch from a minimum number of parts, preferably one. However, since something must be removed to get it through the hole, it is necessary to settle for no less than two pieces. The resulting arrangement is shown in Fig. 3. Integrally machined from plate stock, both the door and the removable segment can be very accurate. Permissible leakage can and should be very small.

As indicated, the perimeter of the door incorporates equally spaced lugs. To assure the mechanical simplicity and reliability previously mentioned, and achievable in no other way, the door is its own latch. In the case illustrated, with 18 external lugs alternating with an equal number of spaces, the rotation between the *open* and *locked* positions is 10 degrees. Door lugs, fitting under jamb lugs, carry pressure with equal safety in either direction.

Figure 4 shows the edge relationship between door and jamb in greater detail. The seal, though small to minimise overlap, is double-flapped to seal in both directions with enough allowable travel to maintain contact during any expected and controllable relative motion. A bulb seal would require high contact pressure to work, possibly demanding a pressure system, another potential failure point. When the only force available is the differential pressure across the closed port, a flap seal is a better choice because its edge is flexible, conforming more easily to irregularities, and it offers more area for pressure to lay it down. Since the seal must lightly slide along the sealing surface when the door is operated, it cannot be allowed to move laterally for fear of tucking under. This is another major reason for making the door round.

Note that the sealing surface is part of a step in the jamb edge. By being so located, below two projecting corners, it is protected from damage by objects bumping the edge as they pass through the opening. The seal is primarily placed in an edge concavity, although, being flexible, it can move unresistingly away from a damage source; in any case, it is also replaceable. As intended, it would be made as an accurate, continuous-loop molding, slightly undersize to fit snugly against its retaining shoulder. Its retention strap would also be continuous like a bandsaw blade, slightly oversize and heat-shrinkable. The shrink temperature must be lower than that which would damage the seal.

Many positioning (or latching) methods can be adopted for this door design without involving much risk as long as the door lugs lie between the jamb lugs when the door is opened and closed and behind them when the door is secured. The mechanism can include an overcenter link arrangement but, in this case, it is only for establishing and maintaining position, not being in any way involved in carrying the pressure load. The pressure load, in fact, acting as it does on the peripheral lugs, makes this hatch difficult, if not impossible, to open when there is any substantial pressure across it. Since it is unsafe to open the door when a pressure differential exists, anything which prevents it should be considered a safety feature. Any added elaboration like an "emergency" over-ride creates its own emergency – an instant need for survival in a vacuum.

No hinges or stowage guide links have been shown because they are likely to be different for different applications and would only serve to confuse matters. In any case, it will be desirable to keep such devices to a minimum – if possible, none at all. As one corollary of Murphy's Law states: "You can't make anything foolproof because fools are too ingenious." However, it might help to counter such ingenuity by keeping airlock hatches as simple as possible, leaving minimum scope for mischance, misadjustment, and operational mistakes.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

STATEMENT OF W. RAY HOOK, MANAGER, SPACE STATION OFFICE, LANGLEY RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Senator PROXMIRE. Mr. Hooks, you represent the National Aeronautics and Space Administration; right?

Mr. HOOKS. Yes, sir.

Senator PROXMIRE. I am very interested in hearing your remarks on this.

Mr. HOOKS. Mr. Chairman and distinguished members of the subcommittee, I appreciate this opportunity to talk to you this morning about the evolution of the space station design and I have an oral statement to make. I would like my written statement to be part of the record.

BACKGROUND OF SPACE STATION

Senator PROXMIRE. Submitted in full in the record.

Mr. HOOKS. The space station itself has been probably one of the most studied systems since the beginning of the agency. To my knowl-

edge, the first three-man office established for the study of a space station was put in place in 1959. The first conference on space stations was in 1960, a joint conference between the Rand Corp. and NASA.

Since that time, in the mid-1960's and again in the late 1960's, the agency entered into what I would call a serious preplanning study phase to determine whether or not designs were available to bring forward to the administration for space station. It initially occurred in 1960 and again in 1969.

A large number of industrial firms were involved in all of those studies and the initial space station that this country placed in orbit in 1973, the Skylab, was a product of some of that early work.

Beginning in 1982, the agency formed a space station task force to move in the direction of a space station, which had been part of the discussions with the new administration as the new administration and President Reagan came on board. This task force started with involvement of eight companies to look at mission requirements for such a space station, and deliberately at that point held in abeyance preconceived notions of space station design until we understood better what we thought a station was to be used for.

MISSION DATA BASE

In 1983, having the results of these eight industrial studies in hand, NASA created what we called a mission data base, which is a compilation of uses for a space station, and launched into its first design definition phase.

In Washington in 1983, a Concept Development Group was established with representatives from all of NASA's centers. Then, with the voluntary cooperation of the eight companies and some additional companies that had been involved in the initial eight mission studies, examined a wide variety of configurations.

CONFIGURATIONS SUGGESTED

The names of these configurations give some hint as to their diverse character. There was a design called the Delta, which was a large truss arrangement with modules forming at the apex of the configurations; one which was referred to as a Planar configuration which existed in solar panels and habitable modules existed in a plane; the Power Tower which is a gravity gradient stabilized configuration; one which was called the Building Block, which depended primarily on the intersection of the habitable modules to form the structural elements of the space station; a spinning space station that was proposed by the Hughes Co.

We also looked at a number of configurations of the module pattern. These were characterized as being triangles, some of them were intersections of three triangles, very much in a similar arrangement as Mr. Harwood's configuration shows there.

There was a Racetrack. There was a Raft. Racetrack meaning modules that connect to each other and form a pattern. A number of these configurations were studied.

The configuration selection process that went forward from that point was based on a number of criteria. First of all, safety and the safety of the crew; the ability to undertake the missions that were proposed for the space station; the long life; low operational cost and low development cost.

In late 1973, this group recommended something that was called the Planar configuration which had the habitable modules and the solar array power system all in a basic plane. It did have articulating arrays.

After the President directed NASA to go forward with the development of a space station program in January 1984, a group of people assembled at the Johnson Space Center. This group has been generally referred to as the Skunk Works. It revisited most of these configurations and selected three for additional study.

The previous Concept Development Group had had the wide open participation of the industry throughout that whole process. The 1984 activity, because it preceded procurement activity, was not quite so open, but did hear presentations from all the perspective bidders at that time.

POWER TOWER

As a result of this study the Power Tower configuration was selected as being slightly superior to the Planar, but the Planar configuration that had been looked at was still a close second.

The Power Tower had a natural stability and natural operating paths for the shuttle to dock frequently with the space station. It also provided a link of structure in which the instrumentation could be placed away from the habitable modules. The habitable modules all leak and the proximity of sensitive instrumentation to that environment is not desirable, so the additional link was plus for the Power Tower configuration.

At the beginning of the phase B that was undertaken, the eight contractors involved were challenged to improve upon the Power Tower configuration and, as a matter of fact, in the three separate activities within the phase B an assessment period, a period of tradeoff and changes, and then finally a preliminary design period leading to our current concept of a space station, a number of changes were made.

DUAL KEEL CONFIGURATION

The now familiar Dual Keel configuration was established and it was established because it did have the inherent capability to grow. It had a truss configuration which was erectable, where the Power Tower previously had not had an erectable truss, it was a deployable truss.

In late 1985, the end of October and the beginning of December 1985, a shuttle flight 61B flew and the EASE/ACCESS experiments were carried out, which demonstrated the ability to erect trusses and beams in space. With this added confidence, the erectable truss configuration that we currently have was adopted.

It also contained the best design features of the previously looked at Dual, Power Tower, and Planar configuration.

Senator PROXMIRE. Mr. Hook, could you summarize in about half a minute because we would like to get to the questions.

Mr. HOOKS. As a result of the *Challenger* accident, the Critical Evaluation Task Force was formed by the Administrator. Again, we went back and revisited all the configurations and came to the point of selecting the current proposed space station Twin Keel configuration.

This is a good station design. It has a great deal of flexibility to grow in many directions. It has the characteristics that the space station needs. It is a space station of reasonable cost and productivity.

I appreciate the opportunity, sir, to come and address you.

[The prepared statement of Mr. Hook follows:]

STATEMENT OF W. RAY HOOK

Mr. Chairman and distinguished Members of the Subcommittee:

Thank you for this opportunity to appear before the Subcommittee this morning to review the evolvement of the Space Station Configuration.

The Space Station Configurations have been carefully examined by the responsible NASA/contractor teams over the past four years. The factors which most influenced this work were safety, requirements of the science, technology, and commercial users, development costs, operational costs, and long-life.

Full detailed competitive Phase B studies of the Space Station were conducted in the late 1960's. From that database, a wide variety of designs of the Space Station were completed in the early 1980's in considerable depth. The major configuration classes that were analyzed were graphically characterized by the following names: The Delta, Big T, Planar, Power Tower, and Spinner (see attached figure). Various patterns for connecting the laboratory and habitat modules called Racetrack, Triangle, Raft, and Lattice were scrutinized in great detail. At specific milestones during the definition of the Space Station program, particular configurations, depicted in the figure, were selected for further in-depth study. In late 1983, the NASA Concept Development Group (CDG), with the voluntary participation of interested aerospace contractors, recommended the Planar configuration, which is also shown, for further study.

During the in-house NASA "Skunk Works" at the Johnson Space Center, many of the configurations which were studied by the CDG were thoroughly examined again in addition to the Planar configuration. The "Skunk Works" recommended the Power Tower Configuration as a point of departure for the Phase B studies which were initiated in late 1984. The Planar configuration was a close contender; however, the Power Tower provided a naturally stable configuration that had superior accommodations for attached payloads and was operationally attractive from a docking and servicing point of view.

During the recently completed Phase B definition studies, improved concepts for locating more payloads on the exterior of the Station, and a desire on the part of many laboratory users to be located near the Station's center of gravity, produced the now familiar Dual Keel configuration. By adding nodes and modules along the transverse boom, this configuration retained many of the inherent advantages of the Planar and the Power Tower configurations.

At the same time, the Dual Keel configuration was selected, a major change was made in the structure of the booms and keels. An erectable truss concept was devised to replace the original deployable concept. The decision was based in large measure on data obtained from the EASE/ACCESS experiment carried out during Shuttle flight 61B, November 19th and December 1st, 1985. Working in the Shuttle payload bay, Astronauts Jerry Ross and Woody Spring assembled and disassembled a number of structural elements including a 45-foot truss with simulated Space Station utilities attached to it. The results were exceptional. This work in "zero G" verified literally hundreds of manhours of simulated "zero G" work carried out in neutral buoyancy tanks at Marshall Space Flight Center, Johnson Space Center, and at a number of contractor facilities.

Based on this new confidence in erectable structures, NASA selected a 5-meter erectable truss configuration to replace the 9-foot deployable concept previously chosen. The erectable truss is cheaper, stiffer, and more amenable to attachment of payloads and other Space Station hardware than the smaller truss. The current truss represents less than 3 percent of the mass of the revised Baseline or enhanced Station Configurations.

I want to emphasize the fact that the present design of the Space Station is an efficient compromise between the competing demands placed on the Space Station. The inherent flexibility of the concept allows for future growth in a number of directions. For example, the number of laboratory modules along the transverse boom could be increased to allow a significant expansion in laboratory science or commercial activities.

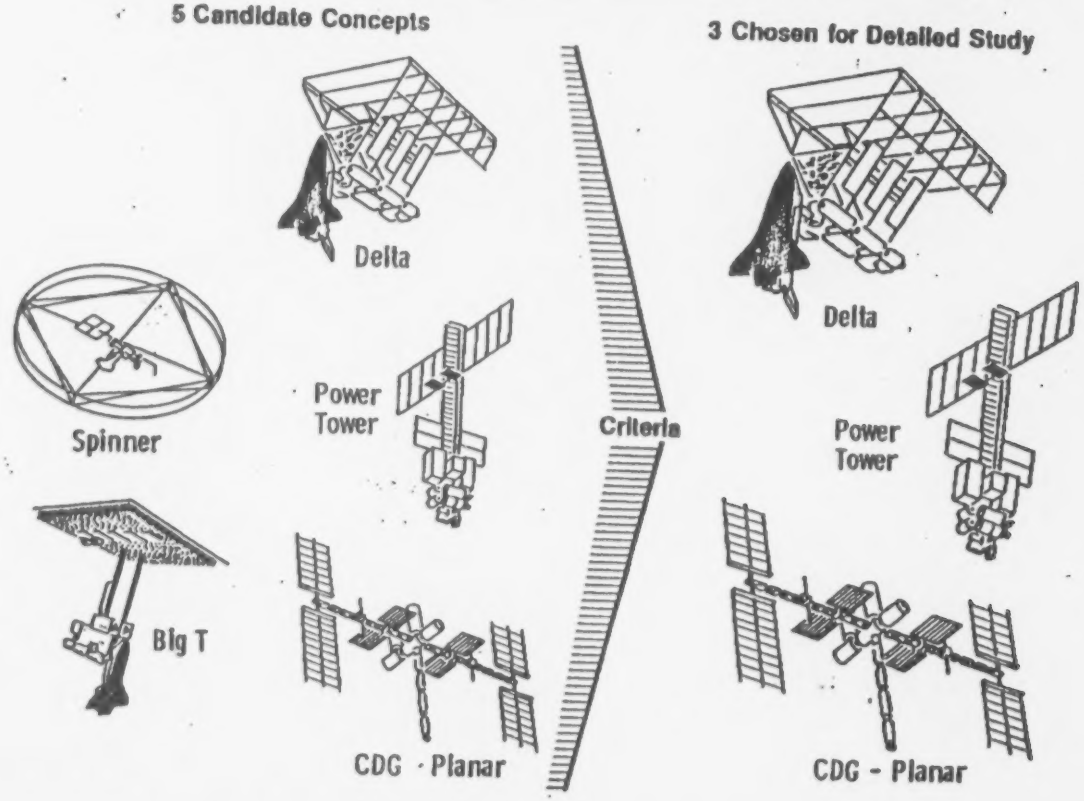
In addition, structure can be added to the keels to provide the necessary fixture for future payloads to be assembled for launch to higher orbits, the moon, or out into the solar system. Additional power may be added to the transverse boom to accommodate future growth to a capability of 300 KW.

One of the strengths of the baseline design is its ability to adapt to innovations and changing requirements. NASA anticipates that innovations, which will allow improvements on the current design, will be forthcoming from the contractors' bids in response to the RFP for the development phase of the program, which was released just last month.

In summary Mr.Chairman, I believe the Space Station will be a unique and a very versatile research laboratory--unique because it will enable a permanently manned presence in space; versatile because it will enable truly diverse capabilities. This enormous range of capability is inherent in the Space Station's pressurized laboratories, accommodations for attached payloads, and free flying unmanned platforms. This research laboratory will add immeasurably to our base of scientific knowledge, stimulate new technologies, and help realize the potential of commercial operations in space.

Critical Evaluation Task Force

CONFIGURATION CONCEPT OPTIONS (SKUNK WORKS)



SOURCE OF SAVINGS

Senator PROXMIRE. Thank you very much, Mr. Hook.

Mr. Harwood, in your testimony you suggest that your plan could lead to a 50-percent cost saving over the currently designed station. We estimate the cost of the space station to be about $15 billion. That means you would save about $7.5 billion.

Exactly where would these savings come? Would they come in labor, materials, capital? Where precisely and how much would be saved in each category?

Mr. HARWOOD. It would primarily come from the simplicity of the system. This is my estimate based upon relative complexity and the problems I see with the adapters I was mentioning previously.

When something must be adapted to grow it is an inhibitor of growth. So, it is impossible to start small. Something that can't grow also can't shrink, which is the reverse process.

Any configuration at all can be started with this much, which is three pressurized nodes, three habitable modules, and one more piece that I don't have a model of which is a power unit which would be put up on the first launch and which would adapt to a port on the next launch that brings up a habitable module.

Senator PROXMIRE. I appreciate that Mr. Harwood. I know that was a difficult question that I asked and you gave me a conceptual answer, not one breaking down the particular costs by item, but maybe you could do that for the record, if you have a chance?

MAN-TENDED INTERIM STEP

Let me ask you one other question. The most difficult aspect of the currently designed space station is the need for a very large investment before the station could be used on a permanently manned basis. There does not appear to be a man-tended interim step, which might be more affordable.

If your basic plan were used, could there be a man-tended phase which we might use for a few years while exploring how best to exploit a fully manned station?

If so, how much smaller would it be, and how much less would it cost compared with your permanently manned minimum configuration?

Mr. HARWOOD. I don't have an army of accountants behind me to substantiate the costs, nor do I have much of an engineering force, and the last time I worked on this job was 3 years ago. But, from what I have been reading, I have some reservations myself about the man-tended part of it. Because of the fact that it is man-tended, it requires the presence of the shuttle.

In ground transportation, we have tried to keep the trucks going by having these modules which contain the cargo transferred from truck to train to ship in order for the transportation system to keep growing.

One of the better justifications for a space station, in my mind, is permanently manned to conduct the experiments on a longer time scale than that has previously been conducted on the shuttle and can allow the shuttle to keep shuttling.

LEAST EXPENSIVE PERMANENTLY MANNED CONFIGURATION

Senator PROXMIRE. What is the cheapest permanently manned configuration you can think of?

Mr. HARWOOD. The very cheapest would be one habitable module and the power unit. Three habitable modules I estimate at about 40,000 pounds a launch, 150,000 pounds of cargo, which allows roughly as much equipment as was on Skylab. That was a pretty capable program, what I would consider a very ambitious starting point, but that starting point can allow you to build any configuration.

Incidentally, these various configurations were mentioned, the Delta, the Power Tower, et cetera. I talked to the man who was the leader of the design team for the Delta. He came and visited me at my place of work.

I had seen in their final report that they had said that these panels were deployable in order to save EVA. My comment was that the trouble with that study is that it had not looked at what the design might be like if EVA were included in the design to begin with.

I told him that I had in my office a toothpick model representing the Delta configuration of the size that he was talking about, it was made of 147 toothpicks, except these were 55 feet long. So, instead of having 6,000 bars in it as the deployable one did, there were 147, 10 of them being habitable modules, or all of them if you take enough time and substance.

The point is, the issue of deployability and erectability came along late in the game and occupied the attention of a lot of engineers when, if you consider growth, the deployable thing extends to a shape that is pretty well predetermined.

Senator PROXMIRE. Thank you, sir.

TRIANGULAR TETRAHEDRAL APPROACH

Mr. Hook, my staff has discussed the basic approach recommended by Mr. Harwood with a number of NASA engineering experts, and they agree that the triangular tetrahedral approach has superior features.

If it were found that this approach could be implemented at substantially less cost and in less time, while providing the type of platform that would support critical life sciences and low gravity research, would NASA be prepared to redirect its efforts to that end?

Mr. HOOK. Sir, I am not at a point to speak to anything other than the technical merits of the two configurations. I am sure NASA would be willing to submit a statement for the record on that.

Senator PROXMIRE. How long would it take NASA to compare the current requirements of the current baseline configuration with a design of the type proposed by Mr. Harwood, and how much would it cost to do that kind of a comparison?

Mr. HOOK. I think based on the work that has been done previously that that comparison could be done relatively easily. There are obvious things with regard to the configuration that you see here.

As Mr. Harwood indicated, it does not consider the addition of a power unit. It has a small number of trusses in it. However, they are quite large, and I believe that a larger size can be demonstrated and it can be assembled by EVA.

Also, it has a blending of structural elements with habitable elements, and I believe there is a structural deficiency in the fact that those elements would expand and contract at different thermal rates, perhaps causing some structural failure.

The proposed configuration here also requires a 60 degree end-cone, which is very inefficient in terms of getting volume up. Most launch vehicles are right certain for cylinders. I think the information is available to assess Mr. Harwood's configuration without a lot of additional cost.

Senator PROXMIRE. Thank you, sir. Before I yield to Senator Garn, let me just say, I want you to know, Mr. Harwood, that I plan to submit your suggested approach to the space station to a committee on the space station that is conducting a critical assessment of the station, including the rationale for design choice.

The committee has been instructed to file a final report by September 1, and the study will cost about $600,000. I am quite sure the group will give your suggestions thoughtful consideration.

Senator Garn?

Senator GARN. Thank you, Mr. Chairman.

Mr. Harwood, I am certainly not capable of getting involved in a technical discussion with either you or Mr. Hook. I don't have that kind of background or experience.

COST ESTIMATE CHALLENGED

I am troubled by your cost estimate, not your design necessarily, but we have a very difficult time in this Congress estimating cost on everyday items of appropriation that have nothing to do with high tech.

I am aware that in projecting cost for whether it was a space shuttle or a space station, you are looking at state-of-the-art technology, you are looking many years down the future as far as not knowing what things will cost, what inflation rates are, and all of that sort of thing.

Even at best with the so-called battery of accountants that NASA has, that Congress has, General Accounting Office, CBO, all of these different agencies, we are often, in fact more often than not, wrong on cost estimates on anything we project around this place.

Yet, what appears to me virtually off the top of your head, again forgetting the technical aspects, you are saying it would cost 50 percent less.

First of all, 50 percent less than what, because I am not confident of the estimates that we have from most anybody who has testified?

Then you, in answer to Senator Proxmire, simply say, "on the basis of complexity." That is a little bit hard for me to look at the cost estimates on that basis, and I don't mean to be rude.

Again, I am not challenging your technical expertise, but it seems to me a 50 percent is off the top of your head or someone else's, and I think in trying to evaluate systems we have to have better than just that 50 percent on the basis of relative complexities.

Do you have any response or can you give us a more detailed response, a breakdown as the chairman asked you for, of how you arrive at that figure. Otherwise, I can give the cost estimate no credibility. I would love to save 50 percent of anything around this place.

Mr. HARWOOD. I think the recommendation has been made for an evaluation, and a more accurate figure can be determined from that.

This 50 percent wasn't entirely off the top of my head. I do know cost estimating people who I work with. I have talked to them about the cost estimations. I showed them what I have done, and their estimate was 50 percent.

That was rather rough, because their time is equally occupied trying to assess the cost of what they are dealing with now, which they say is such an incomplete definition that they have a lot of difficulty in costs. They end up having to find out what its weight is and determine it the way you sell hamburger, so many dollars a pound.

Senator GARN. But you are making my point again. You are saying you haven't been involved for 3 years, people are busy doing something else. All I am driving at is, I don't think that it is necessarily fair to float this figure around.

In our questioning, we question witnesses in detail. We ask for breakdowns. That is all I am saying. You may have a very fine proposal. I am not capable of judging that as a nonengineer. But, unless you can back up this, and that is all I am asking for, there needs to be some breakdowns of costs and estimates rather than just a 50-percent figure, because obviously that is very attractive.

Mr. HARWOOD. I am agreeing with what you say. It is very difficult to get a handle on costs, which is the reason I have as part of the design logic behind this the fact that you can keep the number of elements down, and that you start modestly and allow it to grow to anything.

The ultimate cost of a program that can start small and grow to be very large, but this can be spread over a period of years.

COST BREAKDOWN NOT AVAILABLE

As I say, I don't have a breakdown. I haven't had an army of accountants. I have had people coming, visiting me in my office and explaining things that have been troubling them. These are the other engineers, mostly anonymous, I told you about that I am representing. They are not all engineers either, some of them are cost people who are equally frustrated by the situation they face.

Senator GARN. Again, I think to have credibility, just to come up with a figure, I think we need more than that.

Mr. HARWOOD. I agree we do.

Senator GARN. Then, I would ask some way for you to back it up, some at least detailed estimates, if you think this part of it is going to cost this much and that part of it is going to cost something else.

My point is I am not satisfied with the cost estimates from NASA. My own feeling is that it is going to cost more than even their latest estimates, and I don't think you have to be too bright to figure that out.

That is the normal process around Congress; most everything costs more, including just the operation of Congress costs far more than either Senator Proxmire or I ever thought it would cost for staff and normal operations that isn't high tech.

I don't have much confidence in that. I can't have much confidence in an off-the-top-of-the-head of some anonymous people that think it will cost about 50 percent. We want a good space station, we want the best design that is the most efficient at the least cost.

All I am saying is for your testimony to be credible somehow, we have to have some backup for your assertion that it will cost 50 percent less, before a bunch of my colleagues run off and decide that this is a good design because it will cost half as much.

I don't know whether it will cost 25 percent or 125 percent. I am not convinced you do either. I can't argue with you on the design. I wouldn't challenge your technical background or expertise, but I am challenging what appears to me to be a amorphous opinion off the top of your head.

Senator PROXMIRE. If Senator Garn would yield, I think one of the points, as I understand it, you say that this could be handled in the Harwood approach with 4 shuttle flights, and the NASA approach with 11 flights, but there is a difference there that could explain a large part of the 50-percent cost.

At any rate, as I indicated at the conclusion of my questions at the conclusion of your testimony, we are going to submit this to a committee for them to make an evaluation and a judgment as to whether or not there would be a savings. If so, how much and whether it could do the job that the NASA proposal is doing or could not.

Mr. HARWOOD. Thank you, but I must respond a little myself to the statements of Senator Garn.

It seems the detailed breakdown you have been looking at doesn't convince you very well either. They are pretty amorphous in places too. That is why we really need to have an evaluation.

COMPETITIVE CLIMATE LACKING

Let me add something else; this is an idea that I have proposed, and it is not perfect and nothing is. We always, fortunately, have room for improvement. The problem that concerns me is the lack of a real competitive climate that allows these improvements to emerge at an early enough time.

I have heard comments about, at this late date, let me remind you that all this was ready 3 years ago and it never got to people who are to evaluate it.

Senator GARN. That is a different issue, Mr. Harwood, and I agree with you. You can always look back and find out things would be different and I wouldn't necessarily disagree with you that there has not

been sufficient competitiveness over a long period of time, on these contracts and others.

It is amazing around this body how specific we can be sometimes. When we are opposed to something, how much detail we demand of witnesses and other times how, if we are in favor of what they are saying, we so quickly pass it over.

I just think that as amorphous as those other estimates maybe, at least there is some factual basis for them. I think we need to know the same type of information on your program.

I have no further questions.

Senator PROXMIRE. Senator Grassley?

Senator GRASSLEY. Mr. Chairman, I am going to ask questions of the next panel. I didn't have questions for this panel.

Senator PROXMIRE. Thank you gentlemen for your testimony. It is very helpful.

INTRODUCTION OF WITNESSES

Next we will hear from Mr. Evans, Dr. Grey, Mr. Lanzerotti, Mr. Merrick and Mr. Walker.

Gentlemen come forward and sit at the witness table. We are honored and pleased to have you folks present.

We will do this alphabetically. Our first witness is L.J. Evans, Jr., the Center for Space and Advanced Technology.

Mr. Evans, go ahead.

STATEMENT OF L.J. EVANS, JR., PRESIDENT, CENTER FOR SPACE AND ADVANCED TECHNOLOGY

Mr. EVANS. Thank you, Mr. Chairman.

Rather than read my statement, I would like to submit it for the record, and then just make a few comments.

Senator PROXMIRE. Without objection.

I may have to leave temporarily, but I will be back. Senator Garn, who is far better qualified to conduct this hearing than I am, will take over the chair.

He is in the minority party, but then nobody is perfect. [Laughter.]

Mr. EVANS. We would like to have both minority and majority with us on this one, sir.

BACKGROUND OF MR. EVANS

By way of background, I am president of the Center for Space and Advanced Technology, the company which was founded to help accelerate introduction of advance technology into the market.

I am chairman of the board of the Lou Evans Foundation, a nonprofit organization founded to study and help eliminate institutional barriers to cooperation between our government, the private sector, and academia.

I am a member of the board of directors of a number of companies, several of which are involved in commercial space activities. I am a member of the Space Applications Board of the National Academy of Science.

Previously, I was Chairman of NASA's Space Commercialization Task Force. I was Deputy Assistant Administrator for Commercial Programs at NASA, Chairman of the White House Cabinet Council Commercial Space Working Group, which developed the President's national commercial space policy.

COMMERCIAL SPACE INDUSTRY

I would like to spend just a few minutes discussing the status of the so-called commercial space industry and the importance of the space station to industrial investment in space.

I say so-called commercial space industry, because I think there is a major point to be kept in mind by all of us, and that is outside of communications today there is no commercial space industry.

Companies are not making a profit on doing business in space outside of communications. What there is today is a willingness on the part of the private sector to invest in space research and technology development that could lead to commercial endeavors in space in the future.

I think one of the important things for us to learn from that fact, as I mentioned in testimony several years ago before the Committee on Commerce, Science and Transportation, and that is that we have to be supporting research for 10 to 12 years, if we are to expect a return on our investment.

That means we need consistent long-term positive government policies. We can't be undertaking our policies in fits and starts. If we look at that, we can see that despite the fact that we have not had particularly consistent long-term positive policies, we have a number of companies that are investing in doing research and technology development in space.

The total is over 100 companies. They have invested in excess of $100 million over the last several years. An interesting fact is that 85 percent of those companies are nonaerospace, only 15-percent aerospace.

It is interesting the fields that they are investing in. They include electronics, new metals and alloys, biotechnology, automation and robotics, test instrumentation and remote sensing, propulsion and space transportation, all areas critical to U.S. international competitiveness.

Let's take a look at the impact of having or not having a space station on the future private sector investment in space research and technology development. Critical to this discussion is a fact, and that fact is businessmen abhor uncertainty, at least successful ones do.

INVESTMENT RISKS

Let's quickly review some of the major risks being faced by companies wanting to undertake space endeavors. These risks include the availability, reliability and cost of access to space; the availability, reliability and cost of a place to work in space; the availability, reliability and cost of personnel to maintain, operate and repair equipment; the availability and cost of insurance, the cost of third-party liability; and

the knowledge of potential competition, particularly when it relates to foreign subsidization.

Now, if you look at the status of all of those risks and uncertainties, I think you will agree that it is remarkable that we have had the amount of private sector investment in space research that we have had to date.

After having lead several industrial advisory groups—including most recently one which consisted of 12 CEO's of major aerospace and non-aerospace companies, which reported to Vice President Bush in December—one thing I can say with strong conviction is that space station is absolutely critical to the decisions of major leaders of major companies in this country on whether they will invest on the research and technology foundations for doing business in space.

POLICY INITIATIVES CRITICAL

There are other important policy initiatives which need to be implemented as well, and they include implementing the critical elements of NASA's and the national commercial space policies. It includes undertaking a concerted program to reduce the cost of space transportation utilities and hardware.

It includes a reemphasis of NASA's research and cutting edge technology roles in a maximizing of private sector responsibility for space operations. And finally, and I think almost most importantly, it requires a strong working relationship between the government, industry, and academia.

All of these are important, but one fact is clear; no matter what we do, if industry is not assured of a place to work in space, industry will not invest significant dollars in undertaking space research and technology development today, which is needed in order to lay the foundation for commercial space businesses of the future, which are so important to U.S. international competitiveness.

Thank you.

Senator GARN [presiding]. Thank you, Mr. Evans.

[The prepared statement of Mr. Evans follows;]

STATEMENT OF L.J. EVANS, JR.

Mr. Chairman and members of the Committee, thank-you for the opportunity to be here today to discuss with you the importance of the Space Station to the emerging commercial space industry. I am Bud Evans, President and founder of the Center for Space and Advanced Technology, or CSAT for short. CSAT was founded to help accelerate the introduction of advanced technologies to benefit all Americans. CSAT's mission is to help business, universities, and government work together to commercialize space and other advanced technologies. Because the Space Station is the cornerstone of the U.S. space program, the rate of progress on the Space Station is of particular importance to U.S. competitiveness and the stimulation of the U.S. commercial space enterprise. We are most appreciative of the opportunity to be here today to offer our views on this topic.

The U.S. has always been the world leader in space, particularly in the development of advanced terchnologies for use in space. This leadership has been established only through the great effort and sacrifice that has characterized all of the world's great pioneering achievements. U.S. leadership in space was established with the Apollo program, and continued with the awesome achievement of developing the world's first fully reuseable manned space vehicle and a spectacular series of research missions to explore the planets and to learn more about the heavens and the Earth.

U.S. leadership in space has already brought a broad spectrum of benefits to the U.S. which has been estimated to include over 30,000 secondary applications of aerospace technology spanning nearly the entire range of public needs and conveniences of every day life. Examples of these applications include data processing, telecommunications, electronics, new materials, industrial fabrication methods, fire safety, automation and robotics, and life science improvements for medical applications. And of course, the recent break-through on superconductivity at the University of Houston was a direct outgrowth of NASA funding for its commercial activities program. These gains have had a direct impact on human welfare, industrial productivity, and economic health.

We are by no means alone in space enterprise which so significantly influences world competitiveness. Other major industrialized nations of the free world and the Soviet Union are competing with us actively to achieve leadership in particular areas of space technology. These other nations, often building upon U.S. achievements, recognize the benefits to their own societies of being the first to develop and exploit advanced space technologies.

For example, the European and British programs include development of the Ariane 5 heavy launcher, the SPOT remote sensing satellite, the Hermes manned space vehicle, and the HOTOL horizontal take-off and landing vehicle. These programs are in addition to funding the Columbus manned space modules, which will exploit the advantages of our Space Station. The Japanese, who are also planning a separate module to exploit the potential of the Space Station, are funding development of communciations and remote sensing satellites and expendable launch vehicles, and are reportedly buying many small U.S companies in space-related fields. Moreover, the Japanese and Europeans are spending approximately three and ten times, respectively, more than the U.S. in microgravity research targeted at winning future high technology markets, such as electro-optics. This doesn't even deal with what the Soviets are doing. I also believe you are aware of the awesome capabilities that the Soviets enjoy, capabilities which were demonstrated to the world recently with the launch of a new very heavy lift booster.

In the past, the space programs of every nation have been dominated by government efforts, reflecting in part the magnitude and risk that has often been present in the space enterprise, as well as the national security origins of many space technologies. For many nations, government dominated enterprise is a natural mode of operation and is likely to continue. The U.S. has remained in the lead in many areas of space technology, however, not because of the strength of our government alone, but also because of the strength and creativity of our robust private sector.

The U.S. space program could not have existed but for the strong cooperative teamwork between government, industry, and universities, and the wisdom, energy and creativity of its leaders in all sectors. What is different today is the growing ability and willingness of U.S. private firms to consider independent risk investments in space technologies, recognizing that it may be possible to use the unique attributes of space to research how to develop new materials and to conduct space services on commercial terms and conditions.

Already, we are seeing a broad spectrum of efforts to explore business opportunities in nearly every aspect of space endeavor, from space launch and re-entry vehicles, to space laboratories and research on service facilities and technologies. Products being researched, either for production in space or production on earth, range from new drugs to electronic chip materials to new alloys. Also, on-orbit service business opportunities are being considered which span the gamut of utilities, services and logistics functions that are essential to sustain any community of human activity, whether in space or on earth. Examples of such services include power, fuel, food service,recreation and entertainment, data management, communications and logistics. Many

private firms and universities are actively forming teams to pool their talents in a quest to undertake the preliminary research and technology work necessary to develop realistic options for possible investments in these business opportunities in space.

Most commercial space activities are just now in the planning stages, although space communications has been commercialized since the 1960's. About 100 companies are currently investing private dollars in commercially oriented space research and technology development 1/. Of these, about 15% are from the aerospace industrial sector and 85% are non-aerospace companies. Many of these companies have established cooperative agreements with NASA or are participating in NASA sponsored research consortia. Estimates of investments to-date exceed $100 million. The primary disciplines being pursued by these companies include:

-- 21 companies in **electronics**

-- 27 companies in **metals and alloys**

-- 12 companies in **bioscience**

-- 10 companies in **automation and robotics**

-- 15 companies in **test instrumentation and remote sensing**

-- 12 companies in **space transportation**

1/ This number includes only those companies that have formally announced their investment. Communications companies are not included.

Note also that those companies considering space investments would not only be consumers of the resources of the Space Station, but may include major private investments in building and operating some of the non-critical aspects of the Space Station.

If we are to take full advantage of the significant investments that this nation has made in every major area of space technology, I believe it is essential that these enterprises collectively grow and prosper. With the current fiscal crisis, government alone cannot provide the resources necessary to nurture the constantly growing base of human activity in space that is necessary to keep space as a major contributor to our growing economy and the health and welfare of our people. Perhaps more importantly, it is the initiative and creativity of our private sector that will ensure that the U.S. remains at the forefront in bringing the benefits

of new technologies to practical application. It is the prospect of a growing U.S commercial space enterprise which promises to make, over time, a broad spectrum of services and capabilities available in space for all sectors.

In the same manner that the growth of private enterprise has enabled the extraordinary productivity and standard of living that we enjoy in the U.S., the stimulation of a growing private sector space enterprise will, in turn, make it possible for the nation to more efficiently conduct all U.S. space activities, including basic scientific research and exploration, generic technology development, and manned exploration. Hence, the commitment to a fully capable manned Space Station is not a choice between one sector of space activity or another. In addition to having capabilities designed explicitly to aid the specific needs of each sector, it promises to have its most far-reaching effect in stimulating an industry that in turn will make all aspects of space activity more readily achievable. One such aspect, regarding the conduct of basic space research and manned exploration, will be to make it possible for the U.S. to do more for the same Federal dollars. This is a critical concern if we are to maintain the U.S. leadership position in the face of the continuing and pressing need for fiscal restraint.

As I have noted, these auspicious private sector activities are a relatively recent phenomena. What is stimulating this breadth and potential of space business opportunities to develop is the broad base of space technologies and capabilities that this nation has developed and the U.S. commitment to continued leadership in space. For a strong and growing independent U.S. enterprise of risk bearing investments in space to develop, the private sector must have confidence in three essential fundamentals, (1) the ability to get to and from space efficiently and routinely, (2) the ability to live and work in space, and (3) the ability of government to perform as a reliable partner.

For the first fundamental, access to space, despite the recent difficulties, the Shuttle remains an essential technology to routinely allow manned access to space, and this access will remain an essential element in complementing unmanned space vehicles in order to enable a broad spectrum of business opportunities to develop in space. While no routine major commercial payloads are scheduled to fly on the Shuttle, the Shuttle remains an essential technology to aid in research missions which will explore the most promising technologies which may lead to future space based industries.

The second essential fundamental, to be able to live and work in space, requires that the U.S. have a fully capable U.S. Space Station. The Space Station will be a major culmination of all that the U.S. has learned in bringing man to space, and will provide the essential scale of activity

and capabilities to permit the full spectrum of benefits of U.S. space activities to be realized. Like the early settlement of the U.S., there will be examples where private initiative can establish limited outposts and activities that are noteworthy and important, but the widespread economic development of space cannot occur until the features to be found in any human community can be established in space.

U.S. private efforts will help provide the capital and initiative as the space activites grow. But they cannot be a substitute for the Station. Government will always have a major and complementary role in space, in conducting the basic research which is too broad for the benefits to be captured adequately by individual firms, in providing necessary oversight and regulation, and in providing some of the essential elements of fundamental infrastructure comparable to that which governments routinely provide here on earth. Large-scale U.S. private space enterprise cannot exist alone without a continuing strong and complementary government effort. Also, the government will be one major early consumer of many of the products and services of space based enterprises to permit government to meet its essential missions, and it is in part this business base that will help private firms to compete with other nations and to develop products and services for non-government users. Hence, the third fundamental is that the government be steadfast in its commitments and perform reliably as a partner with private industry.

The importance of the government being a reliable partner is perhaps most apparent by looking at the successes of other competing nations, especially those of Japan and Europe. Borne of the necessity to compete with fewer resources than we enjoy in the U.S., they have learned how to make their private and government sectors cooperate efficiently and reliably. The U.S. has made many outstanding achievements as a result of the efforts of individuals and individual institutions. But major achievements today often require efficient and reliable teaming of the efforts of multiple sectors. This need for reliable and efficient teaming is perhaps more apparent in space ventures than in any other arena of new technology and enterprise, because of the scale, risk, complexity, and inherent need for a strong continuing government role. Hence, the commercial space enterprise provides both a key opportunity and a key test for the U.S.; a key opportunity for the U.S. to develop the inter-sector cooperative skills that it needs to compete in the world in the late 20th century. And a key test -- if we can't do it here, where the clarity of need for the pooling of complementary skills is so obvious, can we really expect to be able to do it in other sectors?

At this point in history, it is the U.S. commitment to a permanent U.S. manned presence in space through a fully capable Space Station that will help to assure the necessary initial infrastructure to allow broad-based and independent U.S space enterprise to grow and prosper.

And it is commitment to the Space Station which business leaders who are considering investments in space look to as the foremost indicator of the strength of U.S. commitment to leadership in space overall.

Unfortunately, business leaders are receiving mixed signals as to the U.S. commitment to the Station and to establishment of the permanent U.S. manned presence in space within about 10 years. In the last several years, the Space Station budget has been repeatedly cut and the Initial Operational Capability date has been delayed. These key uncertainties, together with the unavoidable delays in access to space resulting from the tragic Challenger accident, are creating major obstacles to near-term private space investment and involvement and are seriously increasing the risks of these budding enterprises. Given these circumstances, it is remarkable that U. S. industry has been willing to invest in exploring new space technologies and business opportunities to the extent that it has.

Lets quickly review some of the risks faced by private companies seeking to undertake research and technology and new enterprises in space:

-- Availability and reliability of transportation to space

-- Costs of transportation to space

-- Availability and reliability of a place to operate in space

-- Costs of a place to operate in space

-- Cost, availability, and reliability of personnel to maintain and repair equipment

-- Costs of insuring space operations

-- Costs of third party liability

-- Knowledge and equity of potential competition

Successful businessmen abhor uncertainty. A cursory review of even these partial risks will, unfortunately, reveal uncertainty after uncertainty. This makes it even more critical that the government be a reliable partner. Perhaps more than any other feature, what business leaders require from government in order to justify the investment of their stockholder's funds in space investments is steadfastness in our government's commitment to leadership in space and the programs and capabilities that this commitment represents. Above all, a company planning to perform work in space needs to know that it will be able to

perform according to its plans. Most of the new high potential enterprises that we see for the future require, as a central feature, the existence of a fully capable U.S. Space Station on the schedule now envisioned by NASA. Company executives must be assured of the availability of the Space Station as planned. Without this continued commitment, these promising new enterprises cannot survive and even the existing investment levels will wither.

What is required for the U.S. to remain competitive? In addition to a Space Station which industry leaders are sure will be accessible for their company's research and technology endeavors, a number of policy initiatives on both the NASA and national level are, in my view, required:

-- Implement the critical elements of the President's and NASA's commercial space policies.

-- Undertake a concerted research and technology development program to reduce the cost of space transportation, utilities, and hardware.

-- Re-emphasize NASA's research and cutting edge technology roles and maximize private sector responsibility for space operations.

-- Develop a strong working partnership between government, industry, and academia. Establish more and stronger centers of technical expertise where government, industry, and academia can pool their resources.

-- Provide a national commitment to steady, consistent space policies and adequate resources to maintain America's leadership.

The Congress is now at a critical juncture. With the current deficit crisis, funds for all programs are necessarily limited, and painful choices must be made. But in making these choices, it is essential that this nation make the investments and policies required to protect its future, as well as to meet its current needs. The Space Station is just such a critical investment in this nation's future. Building upon this critical core activity, I can forsee a strong future commercial enterprise bringing the growing benefits to all Amercians. Without timely development of the Space Station as planned by NASA, solid development of this new U.S. enterprise cannot occur and such benefits as may develop will be largely due to the efforts of other nations, which will be first to reap the benefits of their leadership for their own citizens.

From my perspective, I know that both the promise of these ventures and the criticality of the NASA planned Space Station are fact, not theory

or speculation. The essential truth that we must recognize is that, like the legs of the proverbial three cornered stool, America's success in maintaining its historical leadership in technology and in space depends critically upon the ability of business, government, and the academic sectors to function efficiently and reliably together.

We at CSAT are perhaps involved with a wider spectrum of commercial space businesses than any other firm. And if there is one message that stands out from the work that we have been doing every day, it is that this nation must not fail to develop a fully capable manned Space Station by the mid-1990's if we are to achieve the full promise of a first-rank commercial space enterprise and maintain America's historic leadership position in the face of intense and increasing world competition.

I would be pleased to answer any questions that you may have.

AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

STATEMENT OF DR. JERRY GREY, DIRECTOR, SCIENCE AND TECHNOLOGY POLICY, AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

ASSESSMENT OF U.S. CIVIL SPACE PROGRAM

Senator GARN [presiding]. Mr. Grey?

Mr. GREY. The AIAA is grateful for this opportunity to present its views. I will discuss mainly the proposed space station program directly.

I would like to offer these views in the context of an overall assessment that the AIAA recently conducted on the U.S. civil space program. I think a copy of this has been made available to you for the record, and we would appreciate it very much if it were placed in it.

We respectfully request that this be included in the record.

Senator GARN. It will be.

Mr. GREY. Thank you.

The assessment concludes that there is a fundamental inconsistency in attempting to achieve U.S. preeminence in space with budget policies under which civil space program funding declined sharply in constant dollars over the past two decades. Page 16 of this document has a chart, which I think highlights that most graphically.

IMPORTANCE OF GOALS

In this overall context, our assessment finds that a permanently manned space station is a key element in achieving virtually any set of goals whose objective is U.S. leadership in space.

We could, of course, elect to forego the commitment to such a space station, as several people have proposed, by focusing our activities more narrowly on a limited set of goals. I have cited a few of those in my written statement, which I am summarizing here rather than presenting it in detail.

There is merit to these goals, but we must remember it was the United States which in 1961 chose space achievement as the symbol of national capability and resolve. It is our view that we can and must afford the responsibility to future Americans that space leadership provides.

PRESENT GOALS INADEQUATE

These limited goals are simply not adequate. A great deal of effort has been spent cataloging the potential uses for permanently manned space stations; over 150 specific missions were identified.

Every group, however, that participated in those studies emphasized the importance of having a human crew. I have detailed in my written statement the strong arguments that support such a premise and several other witnesses will be addressing that. I won't repeat them here in order to save time.

This need for interaction by humans, though, was demonstrated most effectively during the three Spacelab flights to date, but the limited time, power and lab facilities of shuttle flights do not allow many of the most valuable experiments.

EXPERIMENTS OFFERING ECONOMIC PAYOFF

Often neglected are some of the most promising in terms of ultimate economic payoff, experiments that use the long duration microgravity and high vacuum pumping speeds available only in a space station to study and perfect processes for use on Earth.

These include, for example, and I am sure there are many other examples you will be hearing this morning, the work on crystal growth and thin-film physics by 3M Corp., studies of the crystallization of metals and off-eutectic alloys by John Deere Co., biogenetic synthesis of chemotherapy agents using protein crystals grown perfectly and rapidly in space, by the University of Alabama, and the molecular-beam epitaxial growth of tailored films in the wake shield vacuum, which is being studied by IBM and others.

I stress, the purpose of these studies is research for use in the manufacturing processes on Earth. However, some of them are obviously applicable if they turn out to be fruitful for use in space as has been promoted by many.

But, for interactive laboratory research involving the space environment, and these are research programs that could lead directly to economically important returns, the space station is comparable to wind tunnel facilities used on Earth for studying the physics of air flows. These studies were indispensable in the development of today's $100 billion per year aviation industry.

Yet, despite this promising potential of economic benefit, many question the ultimate real value of science in space, which requires far greater upfront investment than ground based developments.

Unfortunately, there just is no way to guarantee economic payoffs, but history tells us that when a whole new field of physics or chemistry opens, useful products and services have always followed. I can cite

many examples, some of them are, for example, electromagnetism, vacuum technology.

We have today the development of a whole new field of physics which will open up enormous opportunities on Earth and that is the new findings in superconductivity. I see the microgravity and vacuum of space as another example of opening a new physical realm.

NONRESEARCH MISSIONS

Besides science in space, we also have many other nonresearch missions identified for a space station: servicing of space craft and satellites, eventual servicing of orbital manufacturing, eventually technology advancement and so on.

Some people accept this need for orbital research facilities, but ask, "Why not build a much simpler station than NASA has proposed, perhaps launched by a heavy-lift launcher 3 or 4 years sooner, or perhaps build a station in increments"—as the chairman has proposed, first man-tended, and then permanently manned?

The motivation for these suggestions is clear and it is understandable. There are no free world orbital research facilities available today, and with the constrained shuttle manifest, the logjam of experiments will become truly horrendous.

NEED FOR ACCELERATED PROGRAM

Space scientists and others understandably want to get their work done as soon as possible. The AIAA is in sympathy with such scientists. Indeed, we strongly support the call for accelerated, more extensive use of Spacelab and private-sector developments such as the industrial space facility.

Our technical committee on space processing is currently generating a detailed position paper which also supports increased funding and early definition and development of space processing instruments and lab facilities on the space station.

Note that NASA's revised space station plan does recognize this need, calling for some science payloads to be operating, unmanned and unpressurized, by mid-1994—that is a correction in my written statement, incidentally, the typewriter gave us a whole year on the program—and for 7,400 kilograms to be operating, man-tended and pressurized, by early 1995.

Another avenue for obtaining interim orbital experimental time is to use available space on shuttle flights dedicated to the military. It would appear relatively easy for the Department of Defense and NASA to establish a suitable set of operating procedures that would facilitate.

NEW HEAVY-LIFT LAUNCHER

With regard to proposed use of a new heavy lift launcher, although we enthusiastically support the earliest practical development of a next generation heavy lift vehicle, it makes no sense unless it can reduce launch cost significantly and, perhaps even more important as payload costs grow, offer substantial gains in reliability.

The chances of completing such a development as early as 1992 as has been suggested are slim. Just look at the schedule, for example, for the new advanced launch vehicle program, which has a vehicle on-line much later.

Economic considerations also argue against proposals to first build an interim man-tended version of the space station. This has been examined in detail by a number of committees. They have concluded that it doesn't make economic sense.

Although NASA's revised schedule does call for a year of manned tended operations beginning in 1995, if we make this a fundamental premise of the station, it would lead directly into the same trap in which the shuttle development decision ensnared us.

The high cost of shuttle operations that everyone complains about today is a direct result of the 1972 decision to build an interim machine—that is what the shuttle was at the time—and thereby to shave the upfront development cost to the bone. Let's not make the same mistake again.

The space station is likely to be in operation for at least several decades. Its accumulative operating costs will, therefore, obviously far exceed the initial investment. We fervently hope the Congress and administration will allow NASA the upfront investment needed to keep the operating costs low.

Extending shuttle orbital duration is also the wrong way to go. In fact, keeping it up there longer only exacerbates the flight manifest logjam that so concerns us all. It does increase substantially the cost of most experiments.

MICROGRAVITY RESEARCH

It has been suggested that the space station be redesigned to eliminate its microgravity research capabilities altogether and support only a long term goal of landing on Mars. The AIAA does support such a mission eventually and the use of this space station to support it. In fact, the NASA administrator also supports that according to his recent testimony.

We take the position that if the U.S. foregoes the development of microgravity research facilities on the station, invaluable research would not be accomplished by the United States but it will be done in non-United States orbiting laboratories. The economic consequences of that inaction in the light of the history of market penetration by foreign manufacturers in many areas would be disastrous.

The European and Japanese governments are already outspending ours substantially in the commercially important space areas. That is documented on page 22 of this document in some detail. That ominous trend must be reversed.

Clearly the decision on how the United States proceeds with space station development is a judgment call on the part of the Congress and the administration. Other nations have already made that judgment call.

Although the Soviets massive commitment to manned orbital flight is well known, it is not such common knowledge that Europe and Japan, too, have placed their budget bets on manned space flight.

The European Space Agency's commitment to their *Columbus* space station and its support already exceeds $5 billion. There is little doubt that should the United States back down, the Europeans will go it alone, or perhaps even worse, accept the Soviet Union's standing offer to cooperate in their Mir space station activity. I might add that three of the four instruments on the new Quantum space station were built in Western Europe.

JAPANESE SPACE ACTIVITY

Japan, too, has made an unequivocal commitment to the presence of Japanese people in orbit. Besides the Spacelab J, which was originally scheduled for 1988, and the $1.5 billion they have already slated for their ticket into the U.S. space station, Japan has formed four industry consortia as detailed in my written statement and five of the six large Japanese general trading companies have established study committees on commercial uses of the space station.

Note that Japan's fifth generation computer project was preceded by comparable study committees. Sadly for us, as I have quoted in my statement, total Japanese investment in its space station module cost them about a week of the trade imbalance between them and the United States.

So, Mr. Chairman, this nation's judgment call on the space station is up to Members of Congress such as you and to the administration. For the sake of our economic and political future, we urge you to make it a positive one.

Thank you.

Senator GARN. Thank you, Mr. Grey.

[The prepared statement of Mr. Grey follows:]

STATEMENT OF DR. JERRY GREY

The American Institute of Aeronautics and Astronautics (AIAA) is grateful for this opportunity to present its views on the proposed U.S. space station program.

AIAA is a nonprofit professional society dedicated to advancing the art, science, and technology of aeronautics and astronautics and to nurturing and promoting the professionalism of those engaged in these fields. Our membership of over 40,000 is drawn from various levels of American industry, academia, and government as well as from many other nations.

Our views on the space station program are offered here in the context of an overall assessment the Institute recently conducted on the U.S. civil space program (1)*, which we respectfully request be included in the record. The assessment concludes that there is a fundamental inconsistency in attempting to achieve U.S. preeminence in space with budget policies under which civil space program funding declined sharply (in constant dollars) over the past two decades (see p. 16 of Ref. 1). If the U.S. elects to be a leading space-faring nation and to commit itself to a plan commensurate with that objective, civil space budgets must be increased as rapidly as practical to a level required to support it. The AIAA expects to develop its version of such a plan, along with commensurate budgets, and we will make sure this subcommittee receives copies as soon as they are available.

In this overall context our assessment (1) finds that a

permanently manned space station is a key element in achieving virtually any set of goals whose objective is U.S. leadership in space.

We could, of course, elect to forego the commitment to such a space station, as several witnesses have proposed, by focusing our space activities more narrowly on a limited set of goals. One such set might concentrate primarily on observational space science, which has enjoyed huge successes in the past, and on proven commercial satellite technology. Another might focus on the critical need to shrink current federal deficits by curtailing equally critical investments in the science and technology needed to replenish our future tax coffers. A third might be to undertake exciting and imaginative space exploration objectives that we would attempt to accomplish by relying on the space assets of other countries.

There is merit to each of these limited goals, and if it should be decided by the Congress and the Administration that this nation, with its multitrillion-dollar economy, is unable or unwilling to be a leader in space, we may indeed be forced to select one of them. But we should remember that it was the U.S. which in 1961 chose space achievement as the symbol of national capability and resolve.

It is the AIAA's view that we can and must afford the responsibility to future Americans that space leadership implies, and that these limited goals are simply not adequate.

A great deal of effort has been expended in cataloging many of the potential uses for a permanently manned Earth-orbiting

station. Over 150 specific missions in science, applications, commercially oriented research and development, support operations, and technology advancement were identified. I will not attempt to review them here, but during the process of developing the list several important conclusions were drawn.

First, every group that participated in these studies ``emphasized the importance of having a human crew. All consider that 'sophisticated machines' (robots, artificial intelligence, etc.) will not be able to provide the desired capabilities that could be provided by a human crew"...(2). That view, published nearly three years ago, has apparently stood the test of time. Just last month Banks and Black wrote in Science ``there is no practical alternative to using humans...Fully automated repair units or the conduct of laboratory-style space research in remote, unmanned satellites...are decades away" (3).

The need for people to support automated equipment for both space research and research in space is becoming even more important as our scientific goals and missions grow more demanding and complex. The free-flying, man tended Hubble Space Telescope, Advanced X-ray Astrophysics Facility, and Gamma-Ray Observatory, as well as many of the on-board experiments foreseen for the space station ``lead inevitably to the need for repairs or servicing," say Banks and Black (3), citing the salvaging of Salyut 7, the Solar Maximum Mission repair, and Spacelab experiments.

The second important finding on the conduct of research in space was also addressed by Banks and Black: ``Humans are...unique in their ability to conduct laboratory-style

investigations...the more general scientific practice of acquiring information about the behavior of the physical world involves interactive experimentation. Hypothesis, experiment, and initial conclusions follow in iterative sequence until new ideas are finally established. The daily activities of thousands of individuals in terrestrial laboratories involved in physics, chemistry, and biology conform to this methodology and their products give proof of its value" (3). Earth-bound scientists do not want to operate their laboratories remotely, whether 200 overhead or by relay satellite when the laboratory is on the opposite side of the Earth.

This need for interaction by humans was demonstrated most effectively by the science conducted in the three Spacelab flights to date (as well as in the many experiments performed by Soviet cosmonauts on the Salyut space stations). But the limited time, power, and laboratory facilities of Shuttle flights do not accommodate many of the most valuable experiments. Often neglected in the debates on ``space commercialization" are some of the most promising in terms of ultimate economic payoff: experiments that use the unique environment available only on a space station (long-duration microgravity and vacuum) to study and to perfect processes for use on Earth. These include, for example, the extensive work on crystal growth and thin-film physics by 3M Corporation, studies of the crystallization of metals and off-eutectic alloys by John Deere Company, biogenetic synthesis of chemotherapy agents using protein crystals grown perfectly and rapidly in space, by the University of Alabama, and

the molecular-beam epitaxial growth of tailored films in the near-perfect vacuum of a wake shield, being studied by IBM and others.

For interactive laboratory research involving the space environment, which unlike observational science usually leads more directly to economically important returns, the space station is comparable to wind tunnel facilities used on Earth for studying the physics of air flows, which were indispensable, with hands-on human interaction, in the development of today's $100-billion-per-year aviation industry. As Banks and Black wrote, ``Facilities (space station) will therefore be needed that can house technical personnel and specialized equipment in space for an extended duration" (3).

Despite the promising potential economic benefits which may ensue from such research, many still question the ultimate real value of science in space, which requires far greater up-front investment than ground-based developments. Unfortunately there is no way to guarantee economic payoffs, but history tells us that when a whole new field of physics or chemistry opens, useful products and services have always followed. Air Force secretary Edward C. Aldridge (4) has called this ``the orbital Catch-22;" that is, to justify the extra expense of people in space vs that of unmanned systems, it's necessary to justify their presence. Without such justification, there is no basis for developing the manned systems. But to justify man's presence, it is necessary to have him there to prove his utility. There is hence no way to justify a priori the incremental cost (over unmanned systems) of manned systems on the basis of the economic benefits derived from

them.

We have addressed the case for ``science in space" as contrasted with the very different field of ``space science". I will not take the time to elaborate here on the many other (non-research) missions identified for a space station, such as servicing of spacecraft and satellites, eventual servicing of orbital manufacturing or processing factories, technology advancement, etc.

But why must we wait for the full-blown, permanently manned space station proposed by NASA? Why not build a much simpler facility, perhaps launched by a new heavy-lift launcher three or four years sooner, as Banks (5) has suggested? Or build the station in increments -- first man-tended, then permanently manned -- as Congressmen Boland and Green (6) have proposed?

Banks' motivation is clear, and it is understandable. There are no free-world orbital research facilities available today, and with the constrained Shuttle manifest projected for the next half-decade or more, the logjam of experiments awaiting laboratory space will become truly horrendous. Space scientists (and others) understandably want to get their work done as soon as possible.

The AIAA is in sympathy with such scientists. We believe the sooner the U.S. resumes space experiments, the sooner we will reap the economic benefits that research is almost certain to bring. Indeed, we strongly support SESAC's call for accelerated and more extensive use of Spacelab and private-sector developments such as the Industrial Space Facility. Our Technical

Committee on Space Processing is currently generating a detailed position paper which, like SESAC, supports increased funding for basic science in space processing and for early definition and development of space-processing instrumentation and laboratory facilities for the space station. The revised space-station plan (7), incidentally, calls for some 2500 kg of payloads to be operating (unmanned and unpressurized) on the station by mid-1993 (the third shuttle flight) and for 7400 kg to be operating (man-tended and pressurized) by early 1994 (the sixth and seventh shuttle flights).

The AIAA has proposed another avenue for obtaining interim orbital experiment time: use available space on shuttle flights dedicated to the military. It would appear relatively straightforward for DOD and NASA to establish a set of operating procedures that would neither prejudice security nor preclude astronauts from manipulating civil experiments.

But with regard to the proposed use of a new heavy-lift launcher or a fast-track, ``grown-like-Topsy" space station, we must examine the extra cost involved, not only in direct development budgets, but particularly in downstream operating costs. We enthusiastically support the earliest practical development of a next-generation heavy-lift launcher, but such a development makes no sense unless it can reduce launch costs significantly and, perhaps even more important as payload costs grow, offer substantial gains in reliability. The chances of completing such a development as early as 1992, as Banks suggests, are slim. The Japanese H-2, for example, which represents a relatively small technological step beyond their

current H-1, received its go-ahead in July 1984 and will not fly until 1992 -- at a projected cost of $1.5 billion.

Similar economic considerations argue against the Boland/Green proposal to build an interim, substantially reduced-capability initial increment of the space station in order to make space laboratories available sooner than the first-phase station increment proposed by NASA. (NASA's revised schedule does call for man-tended operations by early 1994). Such a course would lead directly into the same trap in which the Shuttle development decision ensnared us. The excessive cost of Shuttle operations that everyone complains about is a direct result of the 1972 decision to shave up-front development costs to the bone. Let's not make the same mistake again. Since the space station is likely to be in operation for at least several decades, its cumulative operating costs over that period will obviously far exceed the initial investment. We fervently hope the Congress and the Administration will allow NASA the up-front investment needed to keep those operating costs low.

Extending Shuttle orbiter duration is also, we believe, the wrong way to go. Indeed, keeping the orbiter up there longer only exacerbates the flight-manifest logjam that so concerns SESAC and the AIAA. For at least the next half-decade the Shuttle turnaround time needs to be cut to the absolute minimum consistent with safety and productivity.

The cost of using an extended-duration orbiter (EDO), in addition to the substantial orbiter modifications required, must also be considered. It was estimated in 1984 (2) that use of the

Space Infrared Telescope Facility for its planned 250-day program would cost $3.6 million per day if done in a series of 30-day EDO flights; in a permanent space station or platform it would cost only $400,000 per day to operate. Similar cost impacts were estimated for materials processing research.

It has been suggested by Bruce Murray and others that the U.S. apply the space-station budget to the manned exploration of Mars rather than use it to build a space station (8). Murray of course recognizes the need for space-station experimental facilities to prepare for such a flight, but argues that we should join with the Soviets on such a mission and use their existing space-station facilities for those aspects of the task. The U.S., he says, might devote its energies and resources to other facets of the mission such as transportation-system development.

In a subsequent statement before this subcommittee (9), Murray, along with Sagan and Friedman, eschews the use of Soviet space stations, apparently concurring with Wheelon's view (10) that exclusive reliance on the Soviets for an essential element of the mission might prove unwise. Sagan, Murray, and Friedman instead call for a space station configuration able to support their goal of landing on Mars. While the AIAA supports such a mission (and the use of the space station to support it) eventually, as does the NASA Administrator (11), we take the position that if the U.S. does forego the deployment of space-processing research facilities on the space station, as Sagan, Murray, and Friedman propose, the invaluable research cited by Banks and Black (3) would not be accomplished by the U.S.

(although it certainly will be done in non-U.S. orbiting laboratories). The economic consequences of such inaction, in light of the history of market penetration by foreign manufacturers in automobiles, steel, electronic appliances, and computer components, would be disastrous. The European and Japanese governments are already outspending ours substantially in such commercially important areas as satellite communications, civil remote sensing, and microgravity research (see p. 22 of Ref. 1, for example). In the interest of sheer economic survival, that ominous trend must be reversed.

In summary, the AIAA reiterates its position (1) that the U.S. should proceed with the development and deployment of a U.S. space station, along with its overseas partners, on a schedule as close to the original 1994 operational target as possible ``commensurate with budget, schedule, and operational constraints". It should be designed to be compatible with both U.S. and foreign expendable launch vehicles and to offer crew emergency return.

Clearly, the decision on how the U.S. proceeds with space station development is a ``judgment call" on the part of the Congress and the Administration as to its utility and its long-term value.

But you must also recognize that other nations have already made that ``judgment call". We all know the Soviet Union has been committed to steady space-station program growth since 1971. Their Mir space station, currently manned for a planned 10-month period by two cosmonauts, bears ample evidence of their

dedication. It was recently joined by an 11-ton module named ''Kvant'' (Quantum) carrying an X-ray observatory, an ultraviolet telescope, a new drug electrophoresis unit, and other experimental equipment (12). Kvant would have failed to dock with Mir, incidentally, without cosmonaut intervention to clear a fouled docking port---further evidence that full reliance on automated systems is not wise. Other modules scheduled to dock with Mir include a materials processing workshop, an Earth resources observatory and a biological/botanical laboratory (12).

Although the Soviet's massive commitment to manned orbital flight is well known, it is not such common knowledge that Europe and Japan, too, have placed their budget bets on manned space flight.

The European Space Agency's (ESA's) commitment to their Columbus space station and its support already exceeds $5 billion (including only the preliminary phase of Hermes, and not including substantial non-ESA national commitments). The AIAA has little doubt that should the U.S. decide to forego a space station plan suitable for multilateral cooperation, the Europeans, albeit somewhat reluctantly in view of the additional cost, will go it alone (13). Or, perhaps even worse for the U.S. economic, national security, and political future, Europe may accept the Soviet Union's standing offer to cooperate in their Mir space-station activities. The French, incidentally, have already proposed informally that Europe study the prospect of early (rather than eventual) development of an autonomous European manned space station rather than enter into an intimate partnership with this country.

Japan too has made an unequivocal commitment to the presence of Japanese people in orbit. Besides the Spacelab-J (originally scheduled for 1988) and the $1.5 billion already slated for its ticket into the U.S. space station, Japan has formed four industry consortia: the seven-company Space Technology Corporation (for electronics-related microgravity research), the Japan Space Utilization Promotion Center (aimed initially at space-station utilization), the 13-company Institute for Experiments -- Free Flyer, and the 50-company Space Technology Research and Development Corporation of Japan. Moreover, five of the six large Japanese general trading companies have established 30-60 member study committees to investigate potential commercial uses of the space station. (I don't have to remind this Subcommittee that Japan's 5th-generation computer project was preceded by comparable study committees). In addition, most of Japan's industrial giants have formal space-station utilization committees: Mitsubishi, Mitsui, Sumitomo, NEC, Fuyo-Marubeni, Nissan, Oki, and Nissho Iwai (14).

And sadly for us, as Davis points out in Aerospace America (14), ``Not that paying for the [space station] module and its launch costs will put a strain on the Japanese. Total investment will comprise only a week or so of the trade imbalance between them and the U.S."

So, Mr. Chairman, this nation's judgment call on the space station is up to members of Congress such as you and to the Administration. For the sake of our economic and political future, the AIAA urges you to make it a positive one.

Thank you for hearing us out, and we will be pleased to respond to any questions you may have.

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STATEMENT OF LOUIS J. LANZEROTTI, AT&T BELL LABORATORIES

MANUFACTURING OF ELECTRONIC MATERIALS IN SPACE

Senator GARN. Mr. Lanzerotti?

Mr. LANZEROTTI. Thank you, Mr. Chairman.

Members of the subcommittee, I would like to thank you for the opportunity to discuss briefly with you this morning some scientific and technical aspects of industrial use of the planned space station. We were requested to address two separate aspects of this topic.

The first of these that I want to address is related to the manufacturing of electronic materials. The second is related to the more general topic of scientific research related to industrial interests, specifically the gain in the processing of materials.

Two aspects of the space environment have specifically been proposed as being of possible importance for the manufacturing of electronic materials on space vehicles. These are the absence of gravity and the high vacuum and pumping speeds that might be attainable by certain space flight techniques.

The first of these, the absence of gravity, the so-called microgravity environment, was especially discussed in the report, "Materials Processing in Space," issued by the National Academy of Sciences in 1978.

This committee at that time stated that it did not discover any examples of economically justifiable processes for producing materials in space. This is the current situation with respect to manufacturing electronic materials as presently being carried but by American industry.

HIGH PURITY SILICON

The world's semiconductor industry is chiefly based upon silicon, and specifically upon the existence of very high purity silicon. At the present time, essentially defect-free silicon crystals can be produced on Earth, at a very small fraction of the cost which would be required in space manufacturing.

The attached to my testimony, and I have colored glossy photographs, which I would like to submit, because they are better than the Xerox copies. The attached scanning electron microscope picture of a silicon crystal grown by molecular beam epitaxy is typical of such high quality crystals presently grown by American scientists in industrial and academic laboratories. The metallic nickel-silicide crystal on top of the silicon crystal is also grown by MBE. The individual rows of atoms in the two crystals are very evident. The interface between the two materials is very sharp. The alignment of the two crystals is very evident and certainly very pretty.

There are no defects in the 10^5 atoms in this photo that includes the depth which the electron microscope probes. The defect rate in silicon crystals grown on Earth is, at most, one per square centimeter, or equivalently about 1 in 10^{15} atoms.

I would like to point out that in NASA brochures for microgravity research more precision needs to be made in effect that defects in electronic materials of the order of 1 in 1,000,000,000 are talked about. On Earth, as I said, the defect rate in silicon is 1 in 10^{15}, or approximately 1 in 10^7 or 10^8 better than were talked about in this brochure.

The present situation for defects in gallium arsenide crystals is not as good as for silicon, but is still rather remarkable; only about 100 electrical defects per square centimeter of material, or about 1 defect in 10^{13} atoms.

This, my colleagues tell me who are involved in manufacturing processes, is fully expected to steadily improve as Earth-based manufacturing processes continue to improve.

Certain types of wake shields tethered to a shuttle or space station have been proposed as offering the opportunity to achieve very high vacuums and very high pumping rates. Such attributes of the space environment have been suggested as ideal for research, admittedly, and also for gas-source MBE, molecular beam epitaxy, manufacturing of electronic materials.

Putting numbers into this proposal, at the present time, show it to be entirely without merit. World-wide, the total integrated circuit production of the whole world is about 10^8 devices per year. Most of those are memory devices.

SILICON WAFERS

A typical IC has an area of about one square centimeter; an average produced silicon wafer has an area of about 500 square centimeters.

Hence, the world presently needs somewhat more than 10^5 such perfect silicon wafers for its IC production. The throughput of a laboratory MBE device, which costs about $5 million, is about one wafer per hour.

Hence, if all the world's silicon wafers were to be made by such a MBE device, which may not even be the most efficient or economical as a matter of fact, only about ten MBE devices will solve the world requirement for IC wafers at the present time.

For a cost of only $100 million, considerably less than the launch cost of the shuttle, complete redundancy could be obtained for MBE manufacture of the yearly required silicon wafers on Earth.

SPACE ENVIRONMENT UNNECESSARY

In summary, the space environment is not necessary at this time for the manufacture of electronic materials, which is a highly competitive, fast moving business whose attributes are low cost, high reliability, and quick response to new research developments which are constantly coming.

However, in contrast, the microgravity environment of space can potentially offer some advantages for certain pure research experiments, which, in all likelihood, will not be related to specific manufacturing concerns.

Research investigations and microgravity environment might include studies of floating liquid zones, double diffuse convection, turbulent and chaotic Systems, reduction of density gradients to investigate specific phase transitions, and critical points in specific materials.

The results of some of these space experiments could likely be of considerable interest in understanding Earth-based experiments. This is scientific.

SCIENTIFIC ASPECTS OF CONDUCTING RESEARCH

I would like to make some comments on the scientific aspects of conducting research, and particularly as one thinks about the space station.

In our laboratory, frontier research problems are largely defined by the individual researcher. If an important research problem requires microgravity, the researcher will seek out this capability; one of my colleagues have.

Research is motivated to a great extent by the internal drive of the investigator. A scientist whose research requires laboratory experiments will often not pursue a problem where the results are years in coming and, more importantly, where he or she cannot readily change, alter, modify, rearrange his or her equipment, sample, parameters.

Ideas provoked by lunchtime discussion are literally pursued into the afternoon and evening. This type of research and this type of laboratory environment is very different than that involved in the nation's highly successful unmanned scientific space flight projects.

In the space station era, materials research in microgravity must be highly responsive to scientific imperatives. Research in the space environment requires assured access to space. Without such access, there can be no science. The best researchers will not be interested.

At the present time, access to space for scientific research, whether for studies of materials or for studies of the universe, is very uncertain. Furthermore, the establishment of scientific capabilities is an evolution-

ary process, simple experiments in the laboratory evolve into more complex ones as understanding increases, ideas develop, and the research transverses into development and then manufacturing.

This should be the attitude toward establishment of the space station and any scientific capabilities to fly on it. Scientific projects should not be carried out just because the space station may exist. In moving forward with the space station, there should not be confusion between ends and means, or there will be no first rate science.

In summary, from our laboratory's viewpoint, the space environment offers no advantage for the manufacturing of electronic materials, at this time. Certain important basis research opportunities in materials science may exist using the microgravity environment available on a space station. However, assured access to space and rapid turnarounds and interactions with experiments are mandatory for the best ideas to be proposed and to be carried out successfully.

Thank you again for the opportunity to be here today.

Senator GARN. Thank you, sir.

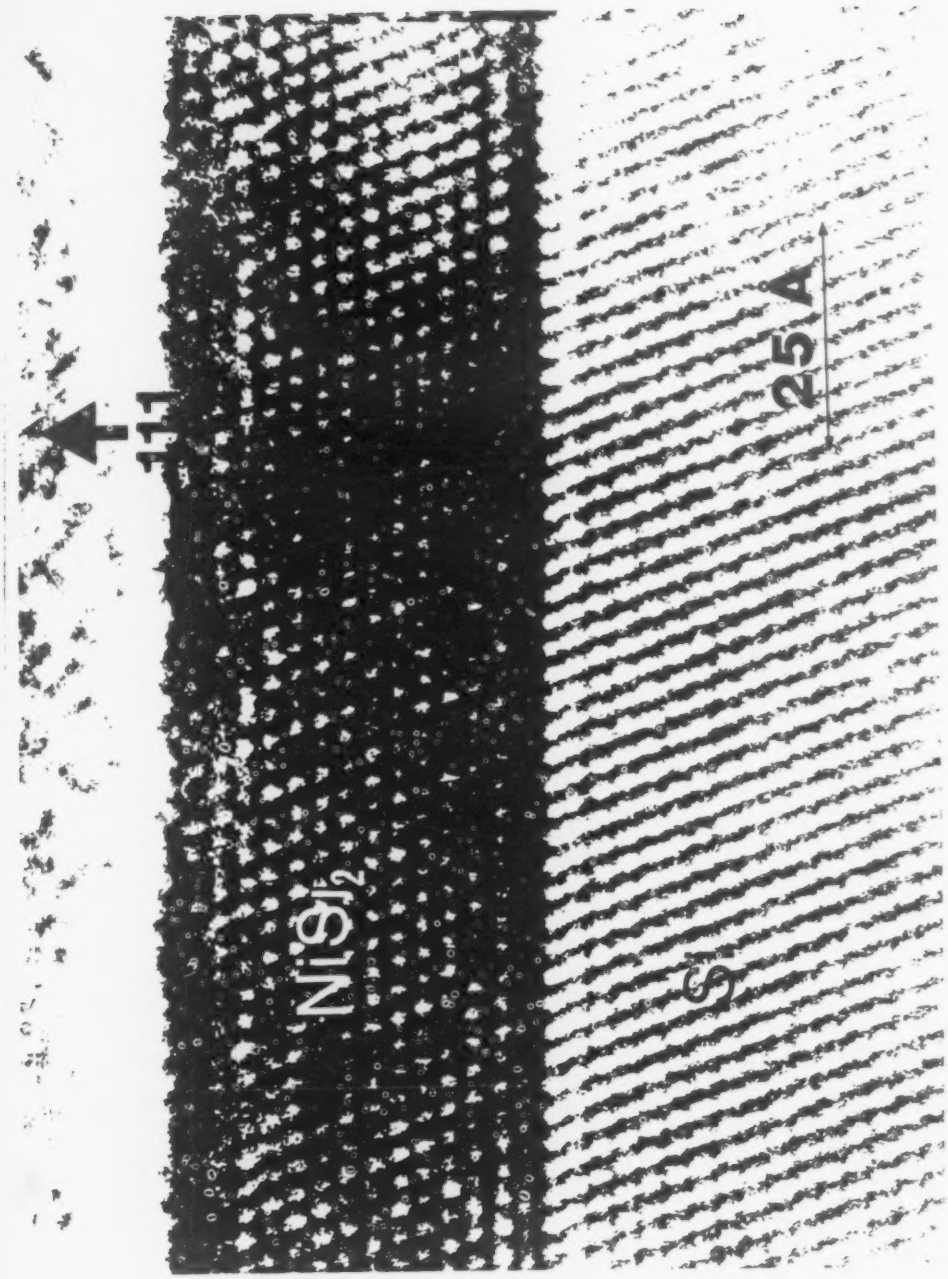
[The prepared statement of Mr. Lanzerotti follows:]

STATEMENT OF LOUIS J. LANZEROTTI

Members of the Subcommittee: I would like to thank you for the opportunity to discuss briefly with you this morning some scientific and technical aspects of industrial use of the planned space station. I want to address two separate aspects of this topic; the first of these is related to the manufacturing of electronic materials and the second is related to the more general topic of scientific research related to industrial interests.

Two aspects of the space environment have specifically been proposed as being of possible importance for the manufacturing of electronic materials on space vehicles. These are the absence of gravity and the high vacuum and pumping speed that might be attainable by certain space flight techniques. The first of these — the absence of gravity (the "microgravity" environment) — was especially discussed in the report "Materials Processing in Space" issued by the National Academy of Sciences in 1978. The Committee stated that it did not "discover any examples of economically justifiable processes for producing materials in space." This is the current situation with respect to manufacturing electronic materials.

The world's semiconductor industry is chiefly based upon silicon, and specifically upon the existence of high purity silicon. At the present time, essentially defect-free silicon crystals can be produced on Earth, at a very small fraction of the cost which would be required in space manufacturing. The attached scanning electron microscope (SEM) picture of a silicon crystal grown by molecular beam epitaxy (MBE) is typical of such high quality crystals (courtesy of J. M. Gibson, AT&T Bell Laboratories). The metallic nickel-silicide



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crystal is also MBE grown on top of the silicon. The individual rows of atoms in the two crystals are very evident; the interface between the two materials is very sharp; the alignment of the two crystals is very evident and very pretty. There are no defects in the about 10^5 atoms in this photo. The defect rate in silicon crystals grown on Earth is, at most, one per square centimeter (or, equivalently, about 1 in 10^{15} atoms). The present situation for defects in gallium arsenide crystals is not as good as for silicon, but is still rather remarkable, only about 100 electrical defects per square centimeter of material, or about 1 defect in 10^{13} atoms. This is fully expected to steadily improve as Earth-based manufacturing processes continue to improve.

Certain types of wake shields tethered to a shuttle or space station have been proposed as offering the opportunity to achieve very high vacuums and very high pumping rates. Such attributes of the space environment have been suggested as ideal for gas-source MBE manufacturing of electronic materials. Putting numbers into this proposal show it to be entirely without merit. World-wide, the total integrated circuit (IC) production is about 10^8 devices per year. A typical IC has an area of about one square centimeter; an average produced silicon wafer has an area of about 500 cm^2. Hence, the world presently needs somewhat more than 10^5 such wafers per year for its IC production. The through-put of a laboratory MBE device — costing about $5M — is about 1 wafer per hour. Hence, if all the world's silicon wafers were to be made by such a process (which may not even be the most efficient or economical), only about 10 MBE devices will solve the world requirement for IC wafers. For a cost of only $100M, considerably less than the launch cost of the shuttle, complete redundancy could be obtained for MBE manufacture of the yearly required silicon wafers.

In summary, the space environment is not necessary for the manufacture of electronic materials, a highly competitive and fast-moving business whose attributes are low cost, high reliability, and quick response to new research developments.

In contrast, the microgravity environment of space can potentially offer some advantages for certain pure research experiments which, in all likelihood, will not be related to specific industrial manufacturing concerns. Research investigations might include studies of floating liquid zones, double diffuse convection, turbulent and chaotic systems, and the reduction of density gradients to investigate specific phase transitions and critical points. The results of some of these space experiments could likely be of considerable interest in understanding Earth-based experiments. In our laboratory, frontier research problems are largely defined by the individual researcher; if an important research problem requires microgravity, the researcher will seek out this capability. Research is motivated to a great extent by the internal drive of the investigator. A scientist whose research requires labaratory experiments will often not pursue a problem where the results are years in coming, and, more importantly, where he/she cannot readily change/alter/modify/re-arrange his/her equipment/sample/parameters. Ideas provoked by lunch-time discussions are literally pursued into the afternoon and evening. This type of research is very different than that involved in the nation's highly successful unmanned scientific space flight projects. In the space station era, materials research in microgravity must be highly responsive to scientific imperatives.

Research in the space environment requires assured access to space. Without such access, there can be no science. The best researchers will not be interested. At the present time, access to space for scientific research, whether for studies of materials or for studies of the universe, is very uncertain.

Furthermore, the establishment of scientific capabilities is an evolutionary process — simple experiments evolve into more complex ones as understanding increases and ideas develop. This should be the attitude toward establishment of the space station and any scientific capabilities to fly on it. "Scientific projects" should not be carried out just because the space station may exist. In moving forward with the space station, there should not be confusion between ends and means, or there will be no first-rate science.

In summary, from our Laboratory's viewpoint, the space environment offers no advantage for the manufacturing of electronic materials. Certain important basic research opportunities in materials science may exist using the microgravity environment available on a space station. However, assured access to space and rapid turn-arounds and interactions with experiments are mandatory for the best ideas to be proposed and to be carried out successfully.

Thank you again for the opportunity to be here today.

Senator GARN. Mr. Merrick, before I turn to you, I would just say that I am aware that Rockwell doesn't approve of Mr. Harwood's ideas, but I wanted to say I appreciated the fact that you did not object to him coming to testify, because I think it is useful that we have different points of view. So I recognize that reasoning is not Rockwell's but, nevertheless, Rockwell did not object to him coming to testify.

ROCKWELL INTERNATIONAL

STATEMENT OF GEORGE B. MERRICK, VICE PRESIDENT, NORTH AMERICAN SPACE OPERATIONS, ROCKWELL INTERNATIONAL

Senator GARN. Please proceed.

Mr. MERRICK. Thank you, Mr. Chairman.

Rockwell has been involved in the nation's civilian space program for over 25 years. We have also been involved in the space station activities, dating from the initial studies in the late 1960's, through the recent definition phase and now the proposal for station development.

Before I offer my views on the station program, let me put it in the proper perspective, as the President has stated:

Space exploration is part of the human adventure. Through it, we challenge ourselves to strive and to achieve. By exploring we are not just finding out more about our physical environment, we are finding out more about the human condition.

It is not a matter of if the boundless frontier of space is explored and developed, the real question is when and by whom. In this relatively new era of space development, opportunities abound for creative minds in research and industry.

NASA's vision is to be commended with its sharp focus on the human spirit's desire to discover, to explore, and to understand. NASA's overreaching goals are to achieve advances in knowledge through space sciences, science in space, and the exploration of the solar system.

REASONS FOR SPACE EXPLORATION

In addition to the strong human inclination to reach out and explore, there are other fundamental motivations for doing things in space that will improve the human condition on Earth. Space systems, using the unique space perspective and the orbital environment, have demonstrated improved productivity on Earth and offer better living standards to its people.

National objectives include broad access to information, worldwide inexpensive communications and navigation, understanding of the processes in microgravity, and Earth monitoring coupled with active and basic applied sciences to improve our productivity and stewardship of our home planet.

The American legacy to lead and explore this new frontier is being severely challenged. Other nations and consortia are aggressively exploiting space. Most notably, the Soviet Union, Western Europe, Japan, and China have major investments in space, in place or planned.

To turn now from continued development of our space infrastructure would severely restrain the U.S. civil space program in this rigorously competitive environment, leading to domination by other nations in areas vital to our standard of living and national security.

ADVANTAGES OF SPACE STATION

Now, I would like to focus on issues concerning the space station. The station will be our gateway to the universe, our foothold in outer space, and the centerpiece of America's infrastructure for decades well into the 21st century.

Providing a permanent manned presence in Earth orbit, the station will dramatically reduce the cost of space operations and eliminate the complete dependence on transportation systems as a temporary quarters for research, servicing and other orbital activities.

The station will be a top notch research facility for both the civil and government communities. It will be an observatory for viewing the Earth and the universe, a natural laboratory of high vacuum and microgravity, and a center for the development of new technologies, materials, and for life science investigations.

It is the necessary staging base and service center for our expanding activities in space ranging from large scientific facilities in Earth orbit to unmanned planetary explorers and ultimately to a return to the moon and a manned mission to Mars.

Moreover, the space station can be a powerful stimulus to the private sector for the development of commercial space initiatives and to the free world nations to conduct cooperative scientific endeavors to the benefit of all.

As our nation's foremost new space program, the station will stand as a symbol of pride at home and prestige abroad. I fully concur with NASA Administrator Jim Fletcher's statement of last October:

> The space station is the key to our future aspirations in space. With its unlimited life span and continuous occupancy, it will transform us from transients in space to permanent residents.

BACKGROUND OF SPACE STATION CONFIGURATION

The current space station's configuration two-phased baseline evolved from a comprehensive phase B definition and preliminary design study which started in April 1985 and was preceded by nearly two decades of analytical, design, and research activities.

Six broadly based industry teams working with four NASA centers under the direction of NASA headquarters performed the phase B effort. In addition, there was significant technological involvement by the academic community and independent research groups. More than 100 organizations have participated.

The major driver of the station configuration is support of the broadest possible user community. Design and operational requirements to satisfy this aim were developed from the inputs of diverse users, representing governmental agencies as well as the civil sector.

Other factors were also of importance in the selection process. These included crew safety, early practical utility, user friendliness, natural evolutionary growth in size and capability to meet new demands, available transportation to orbit, design efficiency, and funding constraints.

No single configuration satisfies all requirements optimally. However, the current configuration is a realistic approach which will assure the necessary conditions for microgravity research in facilities at the station's center of gravity, provide good viewing angles for observational instruments and power arrays with acceptable configuration control requirements, and allow efficient use of space within modules and connecting research nodes.

DUAL-KEEL BASELINE CONFIGURATION

In May 1986, NASA selected a dual-keel baseline configuration for the permanently manned space system. It consisted basically of U.S. laboratory and habitation modules, European and Japanese laboratory modules, four research nodes, solar arrays and a solar dynamic power system, a servicing facility, accommodations for external payloads attached to an extensive truss structure, and two free-flying platforms.

Following a comprehensive, integrated in-house cost review, NASA proposed a two-phased implementation program and some configuration changes to meet funding limitations imposed by both federal fiscal constraints and the need to provide adequate resources for other important NASA activities.

This revised approach was approved by the President in April, and we at Rockwell fully support its fiscal prudence and technical soundness. With a firm national commitment, we are confident that the first elements of the station can be launched by the space shuttle in 1994, with a permanently manned capability established by 1996.

This concept will assure early practical use and hands-on experience with growth matched to user demand and the availability of resources.

As I mentioned earlier, we have been designing space stations since the late 1960's. The use of systems engineering principles has played a strong role in balancing diverse user design technology and economic factors.

Initial configurations were predominantly based on the availability of the 33-foot-diameter Saturn V launch vehicle and constrained by our limited capability and knowledge to conduct EVA activities and assemble systems in space.

During the development of the space shuttle, studies focused on its use as the primary space station launcher, which led to multimodule concept using on orbit, man-assisted assembly. As space program technology advanced and user requirements became better understood, the space station configurations evolved to take advantage of the new technologies and to better satisfy projected utilization requirements.

IMPERATIVE TO MOVE FORWARD

The nation has expended an enormous amount of resources in studying space stations. We could continue our studies to improve or resize the current design, but it is quite evident that we will be impacted by diminishing returns on our investment since the configuration and structure represent only about 15 to 20 percent of the total system cost.

In the meantime, the Soviets will forge ahead expanding the capability of their Mir station and our allies will proceed independently or in collaboration with the Russians. We have little to gain by this strategy and much to lose in terms of technological leadership.

As Senator Hollings so aptly stated on April 21 of this year:

> The time for debating the cost and configuration of the space station should be brought to an end. The administration, the Congress, and our foreign allies are well aware of the design options. It is time to cut metal and cut the debate.

ROCKWELL'S COMMITMENT TO PROGRAM

Let me now comment on our commitment to the program. Rockwell's interest in the space station parallels our participation as one of the nation's major contractors in manned space flight activities since the Apollo program.

We believe the station is essential to the nation's future in space and as such have made a major corporate commitment to support our participation. We established a dedicated Space Station Systems Division in Downey, Calif., headed by a veteran aerospace executive who was Chief Engineer on the Shuttle Orbiter Program. Some of the best Rockwell and most experienced space people form the cadre of this division

which is teamed with Grumman, Harris, Sperry, TRW, United Technologies, and Intermetrics on the station's work package two. In addition, our Rocketdyne Division heads an industry team studying the space station's power system; this includes Ford, Garrett, General Dynamics, Harris, Lockheed, and Sundstrand.

Since the advent of the Apollo program, Rockwell has allocated nearly a quarter of a billion dollars, in 1987 dollars, of its discretionary resources to support manned space flight activities.

Forty percent has been spent on space station studies, research, mockups, simulators and computers, a strong indication of our interest and commitment. Rockwell's space expertise is primarily in the design, development, and construction of major systems, rocket engines, and advanced power units.

USER SUPPLY SUPPORT

However, we have long recognized the importance of support to the users and potential users of our systems. Throughout most of the shuttle program, we have maintained a user supply support organization, which has played an important role in developing interest and understanding among a broad range of commercial companies.

Particular emphasis has been given to the utilization of space for materials processing and support has been provided to such well known organizations as du Pont, John Deere, 3M, and Phillips Petroleum.

In addition, we have developed a multipurpose materials processing laboratory which flew on the space shuttle in August of 1984 in support of NASA's Shuttle Student Involvement Program and conducted a crystal growth and purification experiment.

PUBLIC SUPPORT OF SPACE PROGRAM

Additional experiments are planned on future shuttle flights and the laboratory also will be available for use by other industrial organizations and NASA. A strong and stable foundation of confidence and approval has characterized the public's response to space exploration.

Since the *Challenger* accident, independent surveys have reaffirmed stronger public support. Market Opinion Research's surveys in September 1986 reported the following:

Seventy-five percent approve of U.S. space program; over 80 percent approve of continuing manned space flight, recognizing there will always be risks; over 50 percent oppose cutting NASA's budget; 60 percent approve spending whatever is necessary to maintain space leadership, even to 1 percent of the federal budget; over 75 percent approve of a space station and unmanned planetary exploration as current space goals.

In another more recent national survey, results from the Public Opinion Laboratory at Northern Illinois University in February 1987 showed a strong increase of public sentiment in favor of the space program generally and the shuttle program in particular. Reinforced public support was likewise evident in national, post-*Challenger* accident surveys by ABC, CBS, and USA Today.

Mr. Chairman, the American people are emphatic in their desire to see our nation remain preeminent in space technology. This cannot be accomplished with a national space program budget that has declined by 50 percent in purchasing power in the past 20 years, while other federal budgetary areas which do not have the economic growth potential of space, have increased by up to 20 times their 1965 levels.

The challenge of our nation's space program future is ours. While the opportunity exists for rapid and meaningful space development advances, it is a time of increasingly intense international competition across the full spectrum of space program disciplines.

It is vitally important that the United States meet the international challenge and maintain its leadership in aerospace technology. We need to press forward. We cannot leave the tasks to others.

Thank you.

Senator GARN. Thank you, Mr. Merrick.

[The prepared statement of Mr. Merrick follows:]

STATEMENT OF GEORGE B. MERRICK

Mr. Chairman, I'm George Merrick, Vice President of Rockwell International Corporation's North American Space Operations which is headquartered in El Segundo, California. I have technical cognizance for programs and products covering a wide range of high technologies which are space and energy related.

Introductory Remarks

Rockwell has been extensively involved in the nation's civil space program for over 25 years. We were the prime contractor for the Apollo Command and Service Modules, for the Saturn V rocket's second stage, and for all of the Saturn engines. Our participation in the Space Shuttle program has been equally extensive with prime responsibility for the Orbiter and Shuttle Main Engines and support to NASA in cargo and systems integration as well as orbiter and main engine operations. Rockwell also has been involved in Space Station activities dating from the initial studies of the late 1960s through the recent definition phase and now the proposal for station development. In addition, Rockwell is making important contributions to our national security through space programs such as the Navstar Global Positioning Satellite system and the Teal Ruby advanced surveillance experimental spacecraft.

Before I offer you my views of the Space Station program, let me place it in proper perspective. As the President has stated: "Space exploration is part of the human adventure. Through it, we challenge ourselves to strive and to achieve. By exploring, we are not just finding out more about our physical environment, we are finding out more about the human condition."

It is not a matter of <u>if</u> the boundless frontier of space is explored and developed. The real question is <u>when</u> and <u>by whom</u>. In this relatively new era of space development, opportunities abound for creative minds in research and industry. NASA's vision is to be commended with its sharp focus on the human spirit's desire to discover, to explore, and to understand. NASA's overarching goals are to achieve advances in knowledge through space sciences, science in space, and the exploration of the solar system.

In addition to the strong human inclination to reach out and explore, there are other fundamental motivations for doing things in space that will

improve the human condition on Earth. Space systems, using the unique space perspective and the orbital environment, have demonstrated improved productivity on Earth and offer better living standards to its people.

National objectives include broad access to information, world-wide inexpensive communications and navigation, understanding of processes in microgravity, and earth monitoring coupled with advancing the basic and applied sciences to improve our productivity and stewardship of our home planet.

The American legacy to lead and explore this new frontier is being severely challenged. Other nations and consortia are aggressively exploring and exploiting space. Most noteably, the Soviet Union, Western Europe, Japan, and China have major investments in place or planned. To turn now from continued development of our space infrastructure would severely restrain the U.S. civil space program in this rigorously competitive environment leading to domination by other nations in areas vital to our standard of living and national security.

Importance of the Space Station

Now I would like to focus on issues concerning the Space Station. The station will be our gateway to the universe, our foothold in outer space, and the centerpiece of America's infrastructure for decades well into the 21st Century. Providing a permanent manned presence in earth orbit, the station will dramatically reduce the cost of space operations and eliminate the need to use transportation systems as temporary quarters for research, servicing and other orbital activities. The station will be a top notch research facility for both the civil and government communities. It will be an observatory for viewing the earth and the universe; a natural laboratory of high vacuum and microgravity; and a center for the development of new technologies, materials, and for life science investigations. It is the necessary staging base and service center for our expanding activities in space ranging from large scientific facilities in earth orbit to unmanned planetary explorers and ultimately to a return to the moon and a manned mission to Mars. Moreover, the Space Station can be a powerful stimulus to

the private sector for the development of commercial space initiatives and to the free world nations to conduct cooperative scientific endeavors of benefit to all. As our nation's foremost new space program, the station will stand as a symbol of pride at home and prestige abroad.

I fully concur with NASA Administrator Jim Fletcher's statement of last October: "The Space Station is the key to our future aspirations in space. With its unlimited life span and continuous occupancy, it will transform us from transients in space to permanent residents."

Current Configuration

The current Space Station two-phased baseline configuration evolved from a comprehensive Phase B definition and preliminary design study which started in April 1985 and was preceded by nearly two decades of analytical, design, and research activities. Six broadly based industry teams working with four NASA centers performed the Phase B effort. In addition, there was significant technological involvement by the academic community and independent research groups. More than 100 organizations have participated.

A major driver of the Station configuration is support of the broadest possible user community. Design and operational requirements to satisfy this aim were developed from the inputs of diverse users representing governmental agencies as well as the civil sector.

Other factors also were of importance in the selection process. These included crew safety, early practical utility, user "friendliness," natural evolutionary growth in size and capability to meet new demands, available transportation to orbit, design efficiency, and funding constraints. No single configuration satisfies all requirements optimally. However, the current configuration does represent a realistic compromise which will assure the necessary conditions for microgravity research in facilities at the station's center of gravity, provide good viewing angles for observational instruments and power arrays with acceptable configuration control requirements, and allow efficient use of space within modules and connecting resource nodes.

In May 1986, NASA selected a "dual-keel" baseline configuration for the permanently manned Space Station. It consisted basically of U.S. laboratory and habitation modules, European and Japanese laboratory modules, four resource nodes, solar arrays and a solar dynamic power system, a servicing facility, accommodations for external payloads attached to an extensive truss structure, and two free-flying platforms.

Following a comprehensive, integrated in-house cost review, NASA proposed a two-phase implementation program and some configuration changes to meet funding limitations imposed by both federal fiscal constraints and the need to provide adequate resources for other important NASA activities. This revised approach was approved by the President on April 3, 1987. We at Rockwell fully support it as fiscally prudent and technically sound. With a firm national commitment, we are confident that the first elements of the station can be launched by the Space Shuttle in 1994 with a permanently manned capability established by 1996. This concept will assure early practical use and hands-on experience with growth matched to user demand and the availability of resources.

Alternate Designs

As I mentioned earlier, we have been designing space stations since the late 1960s. The use of systems engineering principles has played a strong role in balancing diverse user, design, technological, and economic factors. Initial configurations were predominantly based on the availability of the 33-foot-diameter Saturn V launch vehicle and constrained by our limited capability to conduct EVA activities and assemble systems in space. During the development of the Space Shuttle, studies focused on its use as the primary Space Station launcher which led to multimodule concepts using on-orbit man-assisted assembly. As space program technology advanced and user requirements became better understood, the Space Station configurations evolved to take advantage of the newer technologies and to better satisfy projected utilization requirements.

The nation has expended an enormous amount of resources in studying space stations and our files contain just about every imaginable concept. We

could continue our studies to "improve" or resize the current design, but it is quite evident that we will be impacted by diminishing returns on our investment since the configuration and structure represent only about 15-20 percent of the total system cost. In the meantime, the Soviets will forge ahead expanding the capability of their Mir station and our allies will proceed independently or in collaboration with the Russians. We have little to gain by this strategy and much to lose in terms of technological leadership. As Senator Hollings so aptly stated on April 21 of this year: "The time for debating the cost and configuration of the Space Station should be brought to an end. The Administration, the Congress, and our foreign allies are well aware of the design options. Its time to cut metal and cut the debate."

Industry Commitment

Let me now comment on our commitment to the program. Rockwell's interest in the space station parallels our participation as one of NASA's major contractors in manned spaceflight activities since the Apollo program. We believe that the station is essential to the nation's future in space and as such have made a major corporate commitment to support our participation. We established a dedicated Space Station Systems Division in Downey, California, headed by Seymour Rubenstein, a veteran aerospace executive who was chief engineer on the Shuttle orbiter program. Some of the best Rockwell and most experienced space people form the cadre of Rubenstein's division which is teamed with Grumman, Harris, Sperry, TRW, United Technologies, and Intermetrics on the station's Work Package 2. In addition, our Rocketdyne division heads an industry team studying the station's power system (which is Work Package 4). This team includes Ford, Garrett, General Dynamics, Harris, Lockheed, and Sundstrand.

Since the advent of the Apollo program, Rockwell has allocated nearly a quarter of a billion dollars (in 1987 dollars) of its discretionary resources to support manned spaceflight activities. Forty percent has been spent on space station studies, research, mockups, simulators, and computers - a strong indication of our interest and commitment.

Users' Support

Rockwell's space expertise is primarily in the design, development, and construction of major systems, rocket engines, and advanced power units. However, we have long recognized the importance of support to the users and potential users of our systems.

Throughout most of the Shuttle program we have maintained a users' support organization which has played an important role in developing interest and understanding among a broad range of commercial companies. Particular emphasis has been given to the utilization of space for materials processing and support has been provided to such well-known organizations as du Pont, John Deere, 3M, and Phillips Petroleum. In addition, we have developed a multipurpose materials processing laboratory which flew on the Space Shuttle in August 1984 in support of NASA's Shuttle Student Involvement Program and conducted a crystal growth and purification experiment. Additional experiments are planned on future Shuttle flights and the laboratory also will be available for use by other industrial organizations and NASA.

Public Support

A strong and stable foundation of confidence and approval has characterized the public's response to space exploration. Since the Challenger accident, independent surveys have reaffirmed even stronger public support. Market Opinion Research's survey in September 1986 reported the following:

- Seventy percent approval of U.S. space program
- Over eighty percent approval of continuing manned space flight, recognizing there will always be risks.
- Over fifty percent oppose cutting NASA's budget, sixty percent approve spending whatever is necessary to maintain space leadership, even to one percent of the federal budget.
- Over seventy-five percent approval of Space Station and unmanned planetary exploration as current space goals.

In another more recent national survey, results from the Public Opinion Laboratory at Northern Illinois University in February 1987 showed a strong

increase of public sentiment in favor of the space program generally and the Shuttle program in particular. Reinforced public support was likewise evident in national, post-Challenger accident surveys by ABC, CBS, and USA Today.

Mr. Chairman, the American people are emphatic in their desire to see our nation remain preeminent in space technology. This cannot be accomplished with a national space program budget that has declined by 50 percent in purchasing power in the past twenty years, while other federal budgetary areas which do not have the economic growth potential of space have increased by up to 20 times their 1965 levels. The Challenge of our nation's space program future is ours. While the opportunity exists for rapid and meaningful space development advances, it is a time of increasingly intense international competition across the full spectrum of space program disciplines. It is vitally important that the United States meet the international challenge and maintain its leadership in aerospace technology. We need to press forward. We cannot leave the tasks to others.

Thank you for the opportunity to speak to you today and I will be happy to answer any questions you may have for me.

McDonnell Douglas Astronautics Co.

STATEMENT OF CHARLES D. WALKER, SPECIAL ASSISTANT TO THE PRESIDENT, McDONNELL DOUGLAS ASTRONAUTICS CO.

Senator GARN. Mr. Walker, I have been trying to see which pin you have on your lapel, and I can't tell from here. So, before you start I need it identified.

Mr. WALKER. Mr. Chairman the pin on my lapel is a stylized conceptual space station program pin.

Senator GARN. I was afraid it might have been one of these other flights, and if it wasn't 51D I would have questioned your judgment. At least it is neutral then, but I would have still expected better judgment coming before me today; you could have at least had our crew patch on.

Mr. WALKER. Mr. Chairman, with all due respect, of course, I recognize that yourself and I are uniquely qualified to wear the symbol of our flight.

Today, I, with all due respect, come before the committee looking toward the future and doing that I certainly recognize the foundation upon which the future is built, and our flight was one of the most important in that regard.

Senator GARN. I appreciate your good judgment in not wearing a past flight pin of some other crew which you participated in.

Please continue.

Mr. WALKER. Thank you, Mr. Chairman. I would like to submit some written testimony for the record, and digest it in verbal form for you.

Senator GARN. It will be included in full in the record.

Mr. WALKER. Thank you, Mr. Chairman.

Senator Grassley, my name is Charles Walker. I am special assistant to the president of McDonnell Douglas Astronautics Co., and I have been privileged to be a crew member on three shuttle missions, certainly not the least of which is the mission that the Senator and I participated in.

PERSPECTIVE ON SPACE PROGRAM

I was part, in those ventures, those flights, of a joint venture to determine the feasibility of specific U.S. manufacturing opportunities in space. I am honored to have the opportunity to present McDonnell Douglas Co.'s perspective on the space station program today.

Today, thousands of industry scientists, engineers and technicians are preparing proposals to NASA for the detailed design, development, manufacture, and delivery of the systems and elements which will make up this nation's permanent space station.

Their companies, and others are also investigating the future utilization of that national research and industrial park that will happen to be located in Earth orbit, the U.S. space station.

SPACE NEWEST AND GREATEST FRONTIER

No one can deny that investing in space is risky business. The U.S. government has historically assumed, initially, large portions of the risk in exploratory ventures, such as the opening of this continent's western frontier or such as the development of commercial aviation.

Now the greatest frontier for exploration and utilization in our history is being opened. The space transportation systems and the space station represent appropriate national investments. As these government assets provide us with guaranteed access to space, industry will follow up on its current initial investments. The space station is a good investment for this nation.

The NASA Space and Earth Science Advisory Committee Task Force on the Scientific Uses of Space Station, abbreviated as TFSUSS, has found that the space station can provide results of great interest to a variety of technical disciplines. These include as minimum, among other possibilities which we have yet to identify, the fields of astrophysics, life sciences, microgravity sciences and earth observations.

I am firmly convinced the physical environment of space will, as have all earthly environments, yield rewarding scientific and commercial applications. Who else thinks this is the case?

COMMERCIAL SPACE DEVELOPMENT

First, aerospace industry leads the parade into commercial space future. McDonnell Douglas has been a leader in commercial space transportation. We also have invested millions of our own dollars in a pharmaceutical purification technology proven in space.

Close behind, with investments in the necessary ground based precursor research as well as results derived from space shuttle missions or planned space based research, are a number of nonaerospace companies. Included in this impressive list are 3M, John Deere and Co., GTE, Kodak, and IBM. Many are participating in nine NASA-sponsored centers for the commercial development of space. These centers are established for the purpose of commercial space opportunities in the 1990's and beyond. Active development can be expected in the areas of automation and robotics, optical and electronic crystals, industrial catalysts, polymers, and biological crystallography.

The contributions of the companies involved must match or exceed the NASA support. Millions of private sector dollars are being invested.

EUROPEAN AND ASIAN ECONOMIC TRADING PARTNERS

Also eager to participate in a space future are our European and Asian economic trading partners. Their aerospace companies are interested in investing, and so are companies outside aerospace.

Soviet Union proudly states that its eighth space station in orbit now is permanently occupied. That demonstrates continuity and a significant commitment. The work going on aboard the Mir complex—pharmaceutical and semiconductor production for example—speaks of their determination to utilize that capability.

There have been calls for this nation to go backward, and once more look at the requirements and the design of the space station. There is no need to retreat.

SPACE STATION MISSION

The space station as presently conceived has a mission, the provision of a permanent presence in space that will permit an orderly conduct of scientific research along with opportunities for scaled production/manufacturing operations and other experiments and demonstrations leading to a productive manned presence in space.

I am living proof that man and science in space go together. Man has a tremendously important role in formulating, observing and fulfilling creative research, and man has a valuable role in modifying and repairing his creations.

My company's analyses and evaluations show that based upon the criterion of equipment and man-days accommodated, the completed and permanently manned space station will accomplish NASA's mission and systems requirements.

The so-called man-tended activities, as differentiated from the permanently manned space station activities, will accomplish considerably less. Our work shows that, in fact, the man-tended concept meets only a small fraction of NASA's total mission requirements.

I have heard assertions that the space station design will not allow serious study of long-term human life in space, or the development of recycling life support systems, or experience in orbital transfer and assembly. Such assertions are without foundation. These results either will be inherent in space station construction and operational experience or will be facilitated with the evolution and growth of the space station.

NEED FOR DIVERSITY IN SPACE STATION

The facility, of course, must be useful, so it must be diverse. There must be pressurized volumes for people to work within, and structure for instruments to peer at the Earth and at objects out in space. There must also be free flying platforms for observations and research or production with specialized requirements. The NASA configuration will provide the needed utility for all these requirements.

Statements that microgravity science and processing provide no meaningful rationale for the space station are also shortsighted. Significant investments made by McDonnell Douglas, 3M, and others to create, fly, and support experimental assets are not made without the expectation of longer term, more capable facilities in the near future.

The many researchers, engineers, and investors who are assigning valuable public and private resources in current low-gravity materials processing research, provide significant evidence that there is fire hidden by the smoke.

The space station is worth pursuing. It will enable a permanent, productive human presence in the unique environment of space. The need for this space research and industrial center, the space station, is to provide a capability for long-term growth and development.

We cannot afford to be shy about facing that need. From space and from the infinite possibilities of the stimulated human mind will come the advances which can fuel this nation's economy for decades to come.

Thank you, Mr. Chairman and members of the committee. I will be privileged to try and answer questions you may have.

[The prepared statement of Mr. Walker follows:]

STATEMENT OF CHARLES D. WALKER

Mr. Chairman and distinguished members of the subcommittee, my name is Charles D. Walker. I am special assistant to the president of the McDonnell Douglas Astronautics Company. I have been privileged to be a crew member on three space shuttle flights as a part of a joint venture to determine the feasibility of specific U. S. commercial manufacturing opportunities in space. I am honored to have the opportunity to present a McDonnell Douglas Corporation perspective on the space station program.

Today, thousands of industry scientists, engineers and technicians are preparing proposals to NASA for the detailed design, development, manufacture and delivery of the systems and elements which will make up this nation's permanent space station. Their companies, and others, are also investigating the future utilization of that national research and industrial park that will happen to be located in earth orbit--the U. S. space station.

Industry does not intentionally invest its stockholders' dollars, or francs, or yen, or Deutschemarks frivolously. Investments are expected to provide some future returns. In the case of space, those returns are certainly in the future. But, because space is a place with properties that just decades ago would have been considered near magic, that future cannot be neglected by the commercial sector of our economy.

Such investments usually begin with tentative first steps. No one can deny that investing in space is risky business. The U. S. government has historically assumed, initially, large portions of the risk in exploratory ventures--such as the opening of this continent's western frontier or such as the development of commercial aviation.

Now the greatest frontier for exploration and utilization in our history is being opened. The space transportation system and the space station represent appropriate national investments. As these government assets provide us with guaranteed access to space, industry will follow up on its current initial investments.

The National Commission on Space said it quite eloquently in its report dated May 1986, and I quote, "Like the early settlers who took advantage of wilderness forts to open the American west, we believe the private sector can make productive use of a space infrastructure established by the government."

The space station is a good investment for this nation. The NASA Space and Earth Science Advisory Committee Task Force on the Scientific Uses of Space Station (TFSUSS) has found that the space station can provide results of great interest to a variety of technical disciplines. These include as a minimum, among other possibilities which we have yet to identify, the fields of

astrophysics, life sciences, microgravity sciences and earth observations. I am firmly convinced the physical environment of space will--as have all earthly environments--yield rewarding scientific and commercial applications.

Who else thinks this is the case? Those who understand the risks best are first to invest. The aerospace industry leads the parade into the commercial space future. McDonnell Douglas has been a leader in commercial space transportation with the Delta launch vehicle and the Payload Assist Module programs. We also have invested millions of our own dollars in a pharmaceutical purification technology proven in space and now awaiting only guaranteed access to space and a profitable product application. Close behind with investments in the necessary ground-based precursor research, as well as results derived from space shuttle missions or planned space-based research, are a number of non-aerospace companies. Included in this impressive list are 3M, John Deere & Company, GTE, Kodak and IBM. Many of these companies--more than two dozen--are participating in nine NASA-sponsored Centers for the Commercial Development of Space. These centers, which deal with a broad range of applications, are established for the purpose of commercial space opportunities in the 1990s and beyond. Active development can be expected in the areas of automation and robotics, optical and electronic crystals, industrial catalysts, polymers, and biological crystallography. The contributions of the companies involved must match--or exceed--the NASA support. Millions of private sector dollars are being invested.

NASA's intent clearly includes private sector involvement with the space station. In the space station request for proposal, released April 24, NASA directs the bidders to, and I quote, "develop innovative initiatives to stimulate, from multiple sources, U. S. private sector investment and involvement in space station development and operations." I am certain all competing companies are actively working this requirement.

Also eager to participate in the space future are our European and Asian economic trading partners. Their aerospace companies are interested and are investing, and so are companies outside aerospace. They include dozens of western European metals, biotechnical, pharmaceutical, glass-ceramic and semiconductor companies. They also include AEG, Volkswagen, Roussel Uclaf and Kayser-Threde. Several of these companies have already invested in spaceflight research on the space shuttle. They are making the necessary early investments with the active encouragement and support of their governments and financial institutions like Germany's Deutsche Bank and Italy's Interbanca. In Japan technical areas targeted for development include optical

electronics, containerless processing of materials and superconducting substances. Five groups have been formed with major trading companies to evaluate and exploit--when possible-- commercial space opportunities not necessarily waiting for the space station. The trading companies include Mitsui and Sumitomo. The member companies number more than 200.

The Soviet Union proudly states that its eighth space station, in orbit now, is permanently occupied. That demonstrates continuity and a significant commitment. The work going on aboard the Mir complex, pharmaceutical and semiconductor production for example, speaks of their determination to utilize that capability.

There have been calls for this nation to go backward, and look once more at the requirements and the design of the space station. There is no need to retreat. The space station, as presently conceived, has as a mission, the provision of a permanent presence in space that will permit an orderly conduct of scientific research. It can provide that capability along with opportunities for scaled production/manufacturing operations and other experiments and demonstrations leading to a productive manned presence in space. I am living proof that man and science in space go together. Man has a tremendously important role in formulating, observing and fulfilling creative research. And man has a valuable role in modifying and repairing his creations.

My company's analyses and evaluations show that, based upon the criterion of equipment and man-days accommodated, the completed and permanently-manned space station will accomplish NASA's mission and systems requirements.

The so called man-tended activities--as differentiated from the permanently manned space station activities--will accomplish considerably less. Our work shows that, in fact, the man-tended concept meets only a small fraction of NASA's total mission requirements. The TFSUSS has clearly stated that the essential need is for, and I quote, "truly long-term, manned capability." That task force found that the concept of man-tended activity aboard the space station, often touted as the rational and economical first step, is and I quote, "of little value."

I have heard assertions that the space station design will not allow the serious study of long-term human life in space, or the development of recycling life support systems, or experience in orbital transfer and assembly. Such assertions are without foundation. These results either will be inherent in space station construction and operational experience or will be facilitated with the evolution and growth of the space station. The facility must be useful. So, it must be diverse. There must be pressurized volumes for people to work within,

and structure for instruments to peer at the earth and at objects out in space. There must also be free flying platforms for observations and research or production with specialized requirements. The NASA configuration will provide the needed utility for all these requirements.

Statements that microgravity science and processing provide no meaningful rationale for the space station are also shortsighted. NASA's Advisory Council stated in a letter to NASA Administrator James Fletcher, dated August 14, 1986, that microgravity science is, and I quote, "an area of considerable commercial potential." The significant investments made by McDonnell Douglas, 3M and others to create, fly and support experimental assets are not made without the expectation of longer term, more capable facilities in the near future. The many researchers, engineers and investors who are assigning valuable public and private resources in current low-gravity materials processing research provide significant evidence that there is fire hidden by the smoke.

The space station is worth pursuing. It will enable a permanent productive human presence in the unique environment of space. Mankind's activities in space will, by human nature, push every discipline of endeavor to new heights. The need for this space research and industrial center, the space station, is to provide a capability for long-term growth and development. We cannot afford to be shy about facing that need. It is opportunity. And it is opportunity that must be seized now if we are to be leaders--instead of followers struggling, and spending heavily to catch up--in the aggressive conversion of space science activities into real, tangible benefits on earth.

From space and from the infinite possibilities of the stimulated human mind, will come the advances which can fuel this nation's economy for decades to come.

Thank you. I will be pleased to try to answer any questions you may have.

Senator PROXMIRE [presiding]. Thank you very much.

You look as if you have recovered from that 7 days with Jake Garn and are in pretty good shape.

Mr. WALKER. No struggle at all.

Senator GARN. That was easy. You have had to put up with me for 12 years. [Laughter.]

Senator PROXMIRE. That is what I had in mind.

DRAIN ON NASA BUDGET

Dr. GREY, I am extremely concerned that the space station program is going to soak up so much of NASA's budget that we will be faced with an agency that is unable to undertake many of the activities you referred to in your prepared statement.

About 7 years ago, you appeared before me in my last year as chairman of the subcommittee, before I was replaced by a far better qualified chairman in Senator Garn. At that time I expressed my concern over the shuttle's drain on the NASA budget in these words, this is what I said:

> The space agency is using so much of its resources in the shuttle program. That takes up a whale of a lot of their funds and that has knocked out other funding. They made a choice, in my judgment a bad choice; maybe not.

You responded:

> I suspect that is an investment in the future and we will find out in 5 years which one of us is right.

Now, which one of us was right, and would you be satisfied if NASA devoted the same proportion of its budget to science in space over the next 7 years as NASA has over the last 7 years?

Mr. GREY. Mr. Proxmire, your research is excellent. I now recall our interchange. I would say that both of us are right. There is a need for the shuttle to do certain things.

Senator PROXMIRE. You ought to be in politics. That is a great answer. [Laughter.]

Mr. GREY. That is your job, sir. I will leave that totally up to you and Mr. Garn and Mr. Grassley.

ROLE OF SHUTTLE IN SPACE

Let me say why I respond to that. Back in 1972, the AIAA conducted an assessment of new space transportation systems. At that time we decried the use of the shuttle as the sole transportation system for the United States. We felt that the shuttle had unique flexibility and capability to do many tasks, which it does have as Mr. Walker and Mr. Garn have pointed out and as we have seen in the rescue of several satellites.

As a launcher for communications satellites, it was an interim measure and without the use of a reusable orbital maneuvering vehicle or space tug, a shuttle is not a useful device although it can perform the function for launching conventional satellites.

Senator PROXMIRE. The problem there, Doctor, is that that indicates that we didn't spend enough money on the shuttle and that doesn't answer my question. We have to make very painful choices in priorities, because it means if we spent more on space transportation we won't have as much money to spend on science.

INCREASED FUNDING REQUESTED

Mr. GREY. Now, we get back then to the fundamental premise of this document which I had asked to be put in the record, and that is that we are not committing enough funds to investing in the future through our space program.

We ask for a doubling of the space science budget in this document. That is, we feel that space science is being parsimoniously treated in current budgets. The space station can be accomplished and the proper science investments can be made.

This country has a multitrillion dollar economy, Mr. Chairman. If we can't use a tiny fraction of that to invest in our future, we need to reexamine our priorities.

Senator PROXMIRE. Don't we have that same problem with respect to education, the same problem with respect to our national security, SDI? There is just no end to the areas where you could make the argument that we have to devote more resources, but you know what the budget situation is. We are tied in with a bill that all three of us voted for, the Gramm-Rudman-Hollings bill, and I think it was the right thing to do.

Mr. GREY. Mr. Chairman, I would like to answer your comment in two pieces. One is the judgment that must be made among the various programs is a terribly difficult task and one reason that I am not in politics is because I would hate to have to do your job for you.

Second, in order to generate the tax revenues that we need for the future, we must continue to invest. Other people around the world are making that investment.

True, we must make very tough judgments as to how much we spend to sustain ourselves today and how much we invest in future activity. Without that future investment there will be no tax revenues in the future, or at least they will be less and that is a tough judgment.

As I have said in my statement, it is really your judgment call as to where the expenditures are made. I am an advocate for one particular area. You will be faced with advocates for many other areas and I think the judgment as to which of those is most critical to this country and its future really needs to be made by you. It is a tough decision, sir, and I appreciate it.

Senator PROXMIRE. Thank you, Mr. Grey.

MAN-TENDED FACILITY AS INTERIM STEP

Mr. LANZEROTTI, I would like to discuss with you the concept of developing a relatively inexpensive man-tended facility as an interim step toward a permanently manned space station.

To give one example, Space Industries Inc., a Houston firm, is prepared to launch a man-tended module from the shuttle in late 1990 or in 1991, given a modest user commitment from the federal government.

Such a facility would provide some experience in the use of space for microgravity experiments and the like, and this experience could be used to design a fully responsive permanently manned station.

The alternative is to go with a highly sophisticated very expensive facility, as we seem to be doing now, without any firm idea as to how it will be used.

Given those two approaches, which would you favor?

Mr. LANZEROTTI. Are you asking that question of me directly or as our laboratory may view that? I don't think our laboratory has a stance on that at all.

Senator PROXMIRE. I am asking you that question directly as a scientist.

Mr. LANZEROTTI. As a scientist and knowing how the scientists in my laboratories operate, I think, it is stated quite well in our statement. I think there are scientific opportunities. There are scientific opportunities in a microgravity environment. There are some very intriguing ones and my colleagues are interested in some of those.

I think that they would approach that, and we do approach that as scientists, in a more incremental manner in terms of understanding the basic underlying physics and chemistry of the process that we are looking at.

Senator PROXMIRE. Mr. Walker, in your prepared testimony you refer to the pharmaceutical and semiconductor production being carried out on the Soviet Union's Mir complex. As I understand it, we could put up the equivalent of a Mir station with one shuttle flight.

COMPETITION WITH SOVIETS

If the Soviets are able to be so productive with such a small facility, doesn't that suggest that we should put a fairly rudimentary space station in the near term in order to compete with the Soviets and use that experience to build toward a more complex station?

Mr. WALKER. No, sir; I don't believe so. The capability that the Soviets show is one of long-term continuity. They have performed experimentation over periods of years, manned presence there for periods of many, many months at a time in order to gain the results that they apparently have.

I think that we would be shortsighted to build a station to perform those same type of rather limited and current technological capabilities at this point. We, in fact, can do that in the short-term on space shuttle mission.

I think we need a permanent facility to implement these research and potentially productive programs on a long-term basis, a much larger scale than the space shuttle and a small station could afford.

ELECTROPHORESIS OPERATION

Senator PROXMIRE. Mr. Walker, I received a letter earlier this week from the vice president for research and development at Ortho Pharmaceutical Corp., Dr. Kiplinger, regarding the company's decision to withdraw from a joint venture with McDonnell Douglas to develop a pharmaceutical product utilizing a new technology for processing in a microgravity environment that was developed by McDonnell Douglas.

Dr. Kiplinger pointed out that it was recognized early in the discussion that a major competing technology could render the microgravity production system economically unsound and, in fact, that is exactly what happened. Dr. Kiplinger added that the process, the electrophoresis operation in space, still represents a highly sophisticated technology for protein separation.

Can you tell us whether any other drug companies are interested in continuing that kind of work?

Mr. WALKER. There are other drug companies interested. We have held some continuing discussions with other firms in this arena.

Senator PROXMIRE. It is not possible to reveal their identity, I understand that, but if you could tell us, we would appreciate it.

Mr. WALKER. Yes. I understand your interest, but I must beg your indulgence in that our discussions with these other companies were prefaced on confidentiality of identification until agreements could be reached.

Senator PROXMIRE. Whenever it is possible, we would appreciate being notified.

SCIENCE AND TECHNOLOGY EXPERIMENTS FUNDING

Mr. Evans, when Administrator Fletcher appeared before the subcommittee earlier this year, I asked him how much NASA planned to spend on science and technology experiments per year once the station was in place. He indicated that that issue was still being studied.

Do you have any estimate, Mr. Evans, as to what NASA should spend on any such experiments each year to maximize the value of the station?

Mr. EVANS. Yes, sir. I think it is important, as you make some of the very basic choices you have to make between priorities that Dr. Grey and you were talking about a minute ago, that we think about where the U.S. will be in terms of international competitiveness.

It becomes very clear as you look at technology and basic research in space that they are going to be in areas that are quite important to our future competitiveness in a number of fields.

Therefore, it seems to me we are going to have to find some way to enhance the amount of resources that we put into those two areas.

The issue is not going to be one of a choice in my opinion between having a place to work in space—namely, a space station—and putting money into science and technology. The issue is, if we are going to do this work effectively over the time that it takes, we have to have both.

Senator PROXMIRE. Let me just repeat the question. It was, do you have any estimate as to what NASA should spend on such experiments each year to maximize the value of the station?

Mr. EVANS. To break them out, I believe that we probably need to, in the material processing arena, end up at about a $200 million level, and we need to ramp up to that over a number of years.

In the technology arena, where we have had a significant increase with the technology initiative, it is probably half the size that it ought to be.

Senator PROXMIRE. That is very helpful. Thank you.

Finally, Mr. Merrick, in April, NASA's Microgravity Materials Science Assessment Task Force made a report to Dr. Sally Ride that made several interesting points.

I would like to quote from a paragraph contained in the executive summary of that task force report:

STATUS OF U.S. RESEARCH EQUIPMENT

Much of the U.S. research equipment now available for use in space flight experiments is of limited capability and of antiquated vintage. The United States has an urgent need to develop more advanced and more versatile instruments and to begin to test and evaluate them on space flight missions before space station is utilized."

Given the current pace and scope of the microgravity science and materials processing program, there is a real likelihood that the United States will not be in a position to utilize space station effectively as a laboratory for basic and applied research in materials science.

Do you agree with that statement, and if so, what sort of an investment do you think NASA should make over the next five years to correct that problem?

Mr. MERRICK. Senator, I feel as though I would be more inclined to react to Mr. Evans' comment about the $200 million investment.

I am probably not a good source to really understand the balance of that sort of investment requirement and the station utilization. Those things are always a balance of the many pressures of budgetary requirements, to pick a number is tough in my estimation.

As I say, I would kind of defer to Mr. Evans' comment about a $200 million investment being a reasonable level.

Senator PROXMIRE. My time is up.

Senator Garn?

Senator GARN. Thank you Mr. Chairman. Let me get back to your first question about who is right, and back up Mr. Grey in saying that you are both right, and that isn't just a politician's statement.

NASA CHOICE CORRECT ONE

I think if anyone examines the record, NASA was forced to make a choice, and I don't think it would have made any difference which way they made the choice. If they had put a higher proportion into science, which I would agree has been neglected over the years, then we would have slowed down the space shuttle.

That would have ended up costing more and you would have had a battery of people in here saying we have neglected manned space flight and these other experiments for science.

I am well aware of Gramm-Rudman-Hollings and the budget difficulties, but when we spend seven-tenths of 1 percent of our entire national budget on an area that has produced untold benefits that cannot be quantified in terms of dollars, I have made this statement so many times, how do you place a value on human life, development of the pacemaker, and things of that nature?

I realize I have a bias to flying and to space, but I think that bias can be proven when people will look at it and start looking at the benefits from some of these expenditures.

Then when we see, as I said, seven-tenths of 1 percent, that is NASA's total budget. That isn't just space. That is aeronautical research. That is high bypass engines. That is supercritical wings. That is all sorts of areas that we get involved in.

I can remember when I was a young freshman Senator and Frank Moss from my state was chairman of the then separate Space Authorization Committee, and Jim Fletcher was then Administrator of NASA.

That authorizing committee at that time promised Mr. Fletcher that NASA would be kept whole for inflation, but budgets were so tight that they couldn't anticipate increases, but could expect to be made whole for inflation. You have heard testimony that in purchasing power they are down 50 percent.

NEGLECT OF SCIENCE

I think you are both right. Science has been neglected, but NASA and what we get from NASA for the future of our country in a lot of scientific areas of the future in space has been neglected.

There is Veterans as well, and I can remember very distinctly a couple of years ago trying to get just $100 million more into NASA's budget and some of the other agencies that we have in this subcommittee and I did it by taking $294 million out of Veterans.

It succeeded in the committee and when we got to the floor it was put back in. That is out of a $29 billion Veterans Administration budget. I didn't think that taking $294 million was any vast ripoff of the Veterans Administration to spread through several other agencies.

That is what we did, and I think you will find, at least in the 6 years I was chairman of this committee when we got our budget ceilings, Veterans and some of the other agencies, HUD, housing programs, are always able to get theirs.

We were looking at the National Science Foundation. We were looking at EPA. We are looking at NASA. We are looking at a lot of programs that didn't have the constituency that Veterans and Housing and other programs did.

So, I think, you have to put it into perspective, and I think it is a very accurate answer to say that both of you are correct, and I happen

to think it is a shame that for an area that will produce so much in the future, a long time after every one of us in this room are long gone flying in space someplace else I suppose, are going to regret the lack of scientific achievements because of our shortsightedness at this point in time.

Charlie, you are a rare individual. You are the only scientist who has been in space three times, and has actually, not from an academic standpoint talking about these processes, but has performed them.

For the benefit of the committee could you describe in a little more detail, the electrophoresis process, and your successes on your three missions?

Don't expect him to give any great detail. I spent 7 days in space trying to get him to tell me exactly what he was doing and what the product would be, and couldn't succeed, and I told him at that time I wished there were more people in Washington that could keep their mouth shut like that. [Laughter.]

But, if you could describe in more general terms the benefits of what you were doing on your three flights?

ELECTROPHORESIS PROCESS

Mr. WALKER. Yes, Senator. Very briefly, what we at McDonnell Douglas Astronautics Corp. have endeavored to do, the joint agreement in a joint venture with NASA, no exchange of monies, but NASA agreeing to support technology to develop a potential commercial effort at purifying biological substances.

We invested our own monies in developing a process called electrophoresis, which is a means of separating biological materials in a fluid flow by means of an electric field to perform the separation, or provide the separation energy. The process works on a continuing basis and, therefore, allows for large-scale production possibilities.

The process is disturbed greatly by gravity. The gravity minimizes the amount of or the purity of materials that can be separated, also the quantity of materials that can be separated. Space affords the advantage in that several hundredfold, because gravity is not a factor there.

We have flown the experimentation seven times. I have been honored to have the opportunity to accompany it to observe, to modify the process, to make it more productive on a real time basis, during three missions. The flights that we flew were very successful.

DIFFICULTIES NOTED

We were not without our difficulties, however, in working progressively through a series of research and development activities, beginning with very simple experimental expectations and very simple biological materials and finally purifying the hormone which we were endeavoring to bring to commercial fruition, arithralprotein, which is a very complex sugar and carbohydrate natural protein.

The efforts that we did on the shuttle included some malfunctions of the equipment and difficulties with the equipment, and I might note

that in those specific cases, one of which occurred on my first mission accompanying the equipment, the multimillion dollar flight mission of our equipment would have been a complete failure, the loss of that investment in time and effort, if I had not had the opportunity to perform the repair, if I hadn't been there to perform the repair activity as it was.

WORK CONTINUING ON GROUND

The results that we obtained have proven the technology. We have a number of patents on the technology. It is in use on the ground in our laboratories and in conjunction with some other researchers. That process does work very well.

We have, in fact, improved the process on the ground based on our experience in space, and specifically with the work in space, and we now await an agreement with a pharmaceutical company, as we are not a pharmaceutical company, but we will provide the service to the biological community that this purification technology can afford.

Senator GARN. One of the things that I am glad you pointed out, and I wanted to have you say that and even reemphasize it more, because on your second flight I was there to be able to observe you and the process and, without knowing anything about it, I was certainly aware that there were.

IMPORTANCE OF PEOPLE IN SPACE

When we get into this argument of whether men and women are necessary and some of our witnesses, of course, think you can do everything with ELV's and you don't need people. I can testify personally, no second-hand information, that men and women are important.

I saw Charlie, Mr. Chairman, be able to make changes even when we had our emergency EVA to try and salvage the satellite, what was necessary for you to power down and slow down your process temporarily for depressurization and all of that, and see you make adjustments on virtually an hourly basis watching that machine function. That, as sophisticated as our robots are and our computers and so on, simply could not have been done without your judgment and your specific ability to make those changes.

I think some of the academics that we have here that are so opposed to manned flight, I would like to take them on a flight and let them watch, get them out of their classrooms and their textbooks, and they might recognize that men and women are rather important to be in space. So, I appreciate you giving us that description.

Thank you, Mr. Chairman, my time is up.

Senator PROXMIRE. Senator Grassley?

Senator GRASSLEY. Thank you, Mr. Chairman.

I am kind of interested, at this point in time, in what some of these things might cost and what the companies involved in the projects, as they are competing for parts of it, might be looking at as cost.

PRIVATE-SECTOR COSTS

I think my questions, then, would be directed to Mr. Walker and to Mr. Merrick. Is it possible at this point for you, as you are going after part of it, to know approximately what your part would cost? What it is going to cost you, as you go through this process that I assume ends up in a bidding process?

Mr. WALKER. We are in a bidding process at this point. Mr. Merrick will chime in here with some additional details, but to answer your question, Mr. Grassley, since we are in a competitive mode, competitive vein, working—in fact, Rockwell International and McDonnell Douglas are competing on the same portion of the space station in one work package, as NASA calls it.

For competitive reasons, I don't want to discuss, and I doubt if Mr. Merrick will want to discuss, the exact costs that we are putting into the endeavor, but we have both stated I believe, we have stated certainly at McDonnell Douglas that we are investing a considerable amount, many millions of dollars of our own monies, to be competitive in achieving the contracts to assist this nation in building a space station.

Mr. MERRICK. Let me add, let's say the last 18 months has been a very concerted effort on the part of the whole industry-NASA team to understand the configuration, understand the requirements, get a good design, get good cost data.

So, we have all contributed in a kind of a togetherness way, which is typical of phase B, because that is really the way to get down to business. In the estimates that have been made to date, we have seen what NASA has come forward with, and we are very comfortable with those, although we don't always know all the details of what all goes into that and the management implications, et cetera.

But, fundamentally, when they get down to estimating the hardware costs, we are participating in those estimates. We don't have any real hang-up and as it was stated, we are competitively now going to submit a bid in July and I would be inclined not to want to discuss that at this time.

Senator GRASSLEY. I can understand that. I think my questions would have led to more specific questions that I will have to understandably ignore at this point out of respect for your positions.

Maybe I can approach it this way, though. Does it look like the costs that you are going to be operating in are within what NASA itself has said they expect things to cost?

COSTS RATIONAL

Mr. MERRICK. I meant to say that I am comfortable with those. So, the process that has gone together now to define the configuration and the attendant cost and we have no real hang up with the fact that those costs are rational and they are coming from the ground.

Senator GRASSLEY. You feel it can be done then within the projected costs?

Mr. MERRICK. Yes.

Senator GRASSLEY. Since you believe that NASA's projected costs are reasonable, then that means that whatever you are bidding, you are going to be bidding within that projected cost?

Mr. MERRICK. Right.

Senator GRASSLEY. Would that be applicable to you too?

Mr. WALKER. We expect to be able to. We do agree at McDonnell Douglas with the cost estimates that NASA has provided publicly, and we expect to be able to work within that and hope to be able to, in fact, lower that cost.

FIXED PRICE CONTRACT

Senator GRASSLEY. Would both of your companies be willing to do it at a fixed price contract?

Mr. WALKER. For McDonnell Douglas, I cannot speak for our contracting people in that regard. I can't speak for us.

Senator GRASSLEY. This question surely isn't invading the privacy of negotiations on whether or not you are willing to do something on a fixed price?

Mr. MERRICK. Let me say, by all means, we would be willing to do this at a fixed price, but that is not quite as simple as sometimes is conceived of. That might be the highest cost way to procure it.

Let's be sure that there are absolutely no changes. There is nothing that evolves. There is no learning process in the development of the station. That you build exactly what you are defined to build and if anything comes down the pike that seems to be a better arrangement say in the long term, but costs a little more up front, you won't see that. That isn't the way these things happen.

Senator GRASSLEY. You understand. I appreciate exactly what you are saying, but also as I have seen in other discussions of this sort, those very same caveats you bring up are also used as excuses for changing and building up costs as well.

I think, I, as a public official, have to take into consideration whether it could be involved in the space station and whether it would be involved in some big defense contract.

Mr. MERRICK. I am a little hard pressed, but we have always been so strapped for funding that I never remember looking for an excuse to build up the cost. We never could get there with the money that was available.

Senator GRASSLEY. I wouldn't want to suggest that it was just industry that would be looking for excuses to build up cost, or to make changes that somebody wants to see as a desirable change.

Mr. MERRICK. I understand the problems that you folks have in your position, but it just doesn't match with the real world as we see it terms of we are constantly struggling with ways of trying to get the cost down because there isn't that much money.

We are trying to get a job done for less than what is normally expected it will cost, and to search around for ways of increasing costs just doesn't fit, and that is the same with the NASA agency. They have

the same problem. We talk about it all the time. We have a million things we want to spend money for, and then you say, "You are padding the cost."

Senator GRASSLEY. I am not sure I am getting anyplace, but even if I am not, I would still like to have Mr. Walker respond, if you could, as your company would see the whole concept of a fixed price. Even though you can't speak for your contractors, you have to know whether or not you see it the same way Mr. Merrick does or not.

Mr. WALKER. I think, generally speaking, we endeavor always and desire to keep the cost down to a minimum. We desire to see cost estimates met.

Again, I cannot speak contractually for what our company is prepared and willing to bid on in the terms of the contract document. I did not come prepared to talk to that.

Senator GRASSLEY. Maybe my point would best be stated to the chairman or to my colleagues here, and it might be a little bit of a takeoff of something I heard Senator Garn say, and I don't think he needs to rebut this, but if he wants to I would welcome it. Even though he is not here now, I would be willing to talk to him about it.

You remember during the part of his conversation in which he said, we thought things were going to cost so much, and we just really knew they were going to cost a lot more. It is almost as if we in the Congress, ourselves, put ourselves in that environment where you just expect more cost and somehow more cost results as opposed to the environment in which I think we ought, as business people, put ourselves in that you shouldn't just assume that things are going to cost more.

Because I think that assumption by public policymakers as opposed to people in the private sector, where you have to make a profit to do business, creates a very bad environment for contracting in any area, let alone space where maybe a new thing like this is even more justified. We even get into that in things that are everyday contracting, it seems like. It is a concern of mine.

Mr. LANZEROTTI. Mr. Grassley, if you will excuse me for interrupting. I am not involved with any of the space station contracts directly and, therefore, I don't have any specific ax to grind.

FIXED PRICE VERSUS COST-PLUS CONTRACTS

I have been involved in research for many years, and in high technology research for many years. The point of fixed price versus cost-plus contracts is the contract is written on both sides. A contractor might agree to do it for a fixed price, but the person who gives that contract must agree to certain terms in order to meet that price.

Senator GRASSLEY. I don't disagree. I agree.

Mr. LANZEROTTI. The second point is, and I think where the difference comes in, we are talking about two things which are different from commercial activities. One is very high technology. Sometimes you don't know in advance, to meet a specific requirement, what it will cost to do that job, and you guess.

Second, you are not in mass production. If a company that makes VCR's guesses in advance they may lose a lot of money on the first 100 they make, but they will make it up on the next 5,000.

Here we are making one unit; if you lose money on the first one that is it. There are two differences in this kind of procurement as compared to, let's call it conventional commercial procurement.

Senator GRASSLEY. It is a problem for us here, because I can appreciate what Mr. Merrick said, do we in Congress want to put business and our bureaucrats in a straitjacket so that if there is something that comes along that is a real good discovery and that ought to be put into it, you curb that opportunity.

I understand the extent to which you have fixed contracts and no changes and all that to protect the interest of both sides does do that. I would have to admit to you, when you go into a new area like this there are probably more reasons to be for it than for something, we will say, in defense where you are making your 3,000th tank as an example.

But anyway, I do appreciate it, because the discussion, although there wasn't anything firm that came out of it, I think it does help me make some very important decisions.

Senator PROXMIRE. If the Senator from Iowa would yield, I want to commend him on this line of questioning. I think it is extremely constructive and positive.

There is no question that a fixed price contract provides a clear incentive for the contractor to hold down his costs. With a fixed price he holds down his cost and he makes a profit, if he doesn't hold down his cost, he has a loss.

That is the one way that you get the kind of discipline that you have in the free sector into government contracting. Of course, with a new product like the space station, it is extraordinarily difficult. When the time comes, with certain components certainly, maybe something like that could be worked out.

I think the Senator from Iowa is exactly on the right track.

Senator GRASSLEY. I think people in industry have to appreciate that Congress has made some bad mistakes in this area of contracting, not being definite enough. We shouldn't be repeating those mistakes.

Senator PROXMIRE. Thank you very much.

I have one question that I would like to ask. I think we should all be clear as to the financial commitment that would be necessary to pursue the construction of a viable space station, including the design of productive equipment for space station use, the support of good space station experimental work, an adequate information processing capability, and so forth, not to mention the continuation of space science and technology efforts not directly linked to the station and the maintenance of an adequate space transportation system.

FIVE-YEAR $53 BILLION BUDGET

The administration has proposed a 5-year budget of $53 billion from 1988 through 1992 to achieve these goals. That is an average of $10.6 billion a year with a maximum annual budget of $11 billion by 1992.

My question is for each of you, maybe you could answer briefly. Is this adequate to get the job done and, if not, what do you think is needed?

Let's start, as we did before, with Mr. Evans and go right through it alphabetically.

MR. EVANS FAVORS 50-PERCENT INCREASE

Mr. EVANS. Mr. Chairman, my sense in sitting through a number of meetings at the Space Applications Board of the National Academy and in sitting through a number of meetings in relation to the technology initiative in space and so on, and without extensive knowledge on the fixes to the shuttle, et cetera, that we need to make over the coming years, but just looking at the high tech end of it, is that we are probably about 50 percent short on the amount of money that is needed in those areas.

Senator PROXMIRE. So you would have to double the amount to do the job right? In other words, instead of $10.6 billion a year it should be $21.

Mr. EVANS. Fifty percent, sir.

Senator PROXMIRE. We would have to increase it 50 percent?

Mr. EVANS. Yes, sir.

Senator PROXMIRE. So it should be $15 to $16 billion a year?

Mr. EVANS. Yes, sir.

Senator PROXMIRE. Yes, sir, Mr. Grey.

MR. GREY CITES $14 BILLION LEVEL

Mr. GREY. Mr. Chairman, the AIAA has made an estimate in its document that a growth of forty percent, as soon as practicable, over the fiscal year 1987 budget, which was approximately $9.5 billion, would be appropriate, followed by a growth approximately at the rate of the gross national product.

Senator PROXMIRE. So, the first year you would have to go from roughly $10 billion to——

Mr. GREY. As rapidly as practicable. You can't go from $10 billion to $14 billion in 1 year. That is not practical. Over a period of perhaps 2 to 3 years, it should grow to the $14 billion level; yes.

Senator PROXMIRE. Is 5 years enough?

Mr. GREY. I can't tell you that exactly, but it is the range of a few years is all I could say.

Senator PROXMIRE. Mr. Lanzerotti?

MR. LANZEROTTI AND MR. WALKER: 50-PERCENT INCREASE

Mr. LANZEROTTI. My expertise basically covers what budget is currently included in the Office of Space Science and Applications. I do not have terrific insight into the fixes for the shuttle, nor do I have

tremendous insights into the cost of the space station and other technology initiatives.

Senator PROXMIRE. But, in the area where you have the expertise, can you give us an estimate of what percentage increase that would need?

Mr. LANZEROTTI. Yes. Over the 5 years, I would say that the budget for the Space Science and Applications, which includes microgravity and life sciences, should approximately double from its present approximate $1.5 billion.

Senator PROXMIRE. That would also be about a 50-percent increase on the average, if it doubles?

Mr. LANZEROTTI. I think that is correct.

Senator PROXMIRE. Mr. Merrick?

Mr. MERRICK. My reaction would be kind of limited to the shuttle and the station, kind of nonrecurring costs, because I think those are reasonable estimates and I don't have any basis for saying that that is low or high.

I think the part where the lack of commitment comes or the utilization and ops costs downstream that I am not sure I would be a good source. For those that I am familiar with, shuttle and near term station, I think that those are reasonable numbers.

Senator PROXMIRE. Mr. Walker?

Mr. WALKER. Mr. Chairman, it is my judgment that in the areas of space science, I also, agreeing with Dr. Lanzerotti, that a doubling of space sciences on an annual basis ending up at a doubling in some years out is most appropriate to keep this nation in a scientific role of leadership and developing the possibility of applications.

I think in terms of technology that the order of a 50 percent increase in funding levels, beginning as soon as practical and building up to that 50 percent increase over the projected annual budget level, is appropriate again to keep this nation in an economic and technical leadership role and to provide the potential for the advances and the economic benefits that we have learned and a variety of disciplines will come from these activities.

SOURCE OF FUNDING QUESTIONED

Senator PROXMIRE. Now, let me ask you to put on your hat as a citizen and not as a scientist or an expert. Where would you get the money? Would you get it from a tax increase, maybe a corporate tax increase? Would you get it from a personal income tax increase, by eliminating social programs? How would you get it?

Mr. WALKER. Speaking as a citizen, I have a difficult time every month balancing my own checkbook, so the answer to the question may not have that much credibility when it comes to the national budget.

Quite honestly, and without jocularity, I would state that when you look at the investment coming out of my pocket for the future, as my pocketbook contributes to the national budget, the space station as just an example here will cost me 2 cents a day for construction, support, and operation.

In the order of 2 cents a day, that is 2 to 4 M&M's out of a package. That is parking for about 4 minutes here in the Washington area. I think that personally, I could afford not only that but a little more in order to give this nation a viable and valid future as space and aeronautics has shown to provide and I believe can provide in the future.

Senator PROXMIRE. We are gathered in a building which is named after a great Senator from Illinois, Everett Dirksen, who observed that a billion here and a billion there and pretty soon you are talking about real money.

You gentlemen, and your response particularly Mr. Walker, indicates that if we double this over a period of years, and add a few billion, that it is only M&M's. The trouble is, you see, these M&M's add up and we just have to say, "No, no, no," again and again, instead of following President Reagan we have to follow the directions of Nancy.

Thank you gentlemen, very, very much for your testimony. It was very helpful.

CONCLUSION OF HEARINGS

That concludes the hearings. The subcommittee will recess and reconvene at the call of the Chair.

[Whereupon, at 12:27 p.m. Tuesday, May 20, the hearings were concluded and the subcommittee was recessed to reconvene at the call of the Chair.]

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